Programação Imperativa

LEI, 2023-24

Aula 1

Avaliação

- Época normal
  - 80% Teste: 16 Maio
  - 20% Mini-testes
    - Nota mínima 25%
    - Online: 6 Mar, 10 Abr, 24 Abr (4ªs às 19h00 no BB)
    - Presenciais: 18 Mar - 22 Mar, 29 Abr - 3 Mai (aulas TP)
- Época de recurso
  - 100% Exame: 6 Junho

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  - Manuel Barros (TP5, TP7)
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  - Catarina Machado (TP9)

Haskell

- Linguagem de programação de uso genérico
- Funcional
- Estaticamente (fortemente) tipada
- Interpretada e compilada
- Alto nível
- Criada em 1990 por um comité

C

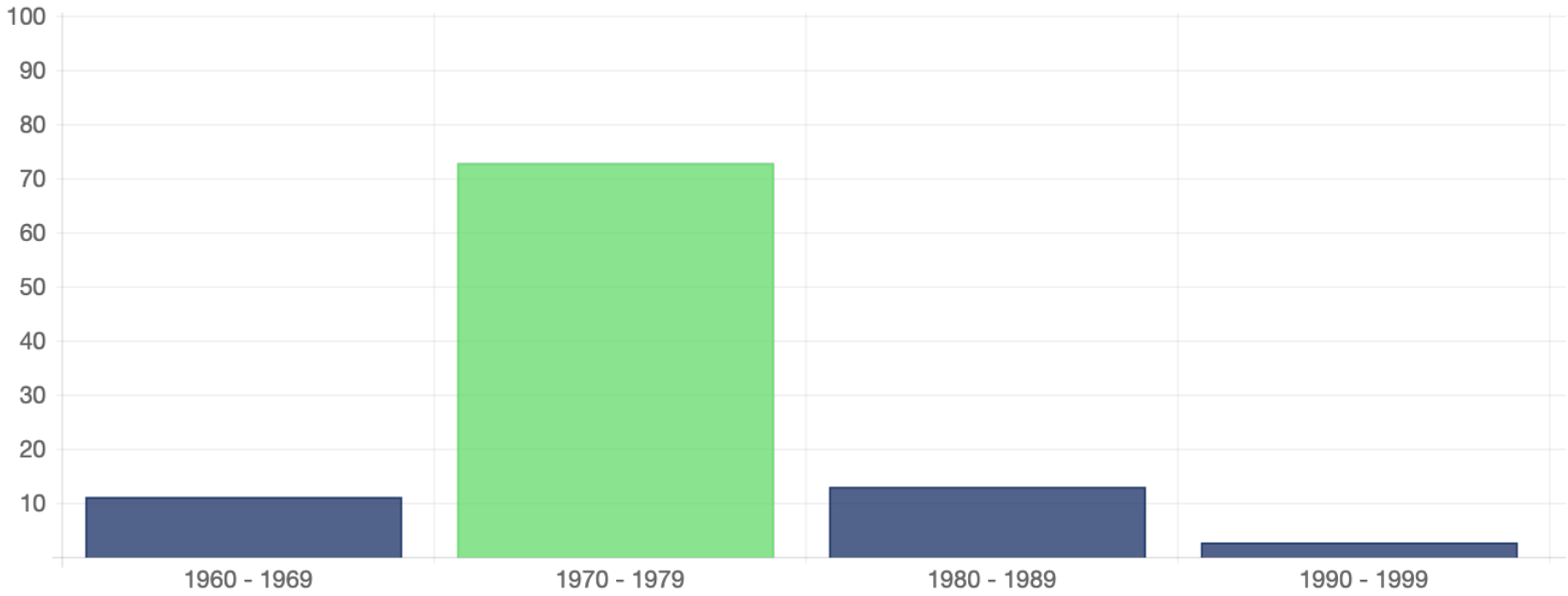
- Linguagem de programação de uso genérico
- Imperativa e procedimental
- Estaticamente (fracamente) tipada
- Compilada
- Baixo nível
- Criada em ???? por Dennis Ritchie


QUIZ!

#0 Em que década foi criada a linguagem C?

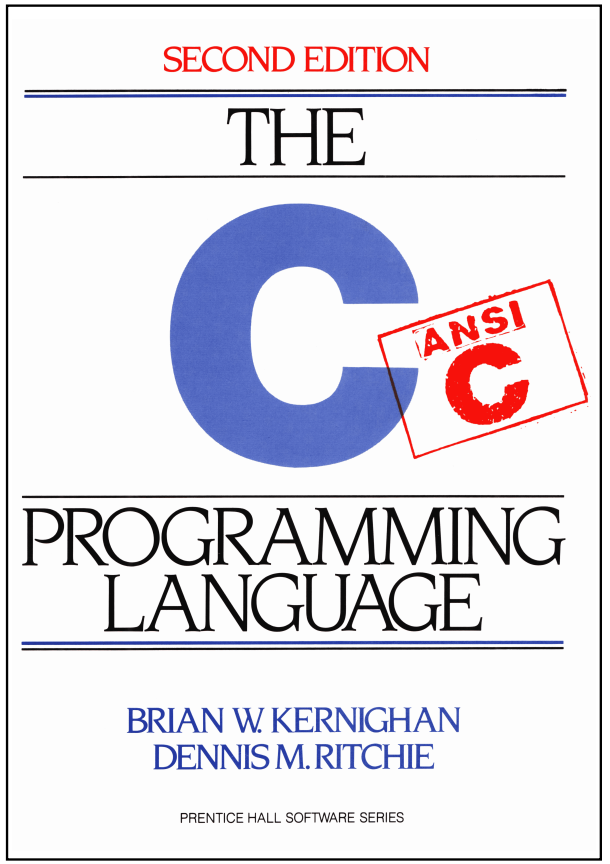
- 1960 - 1969
- 1970 - 1979
- 1980 - 1989
- 1990 - 1999

#0 Em que década foi criada a linguagem C?

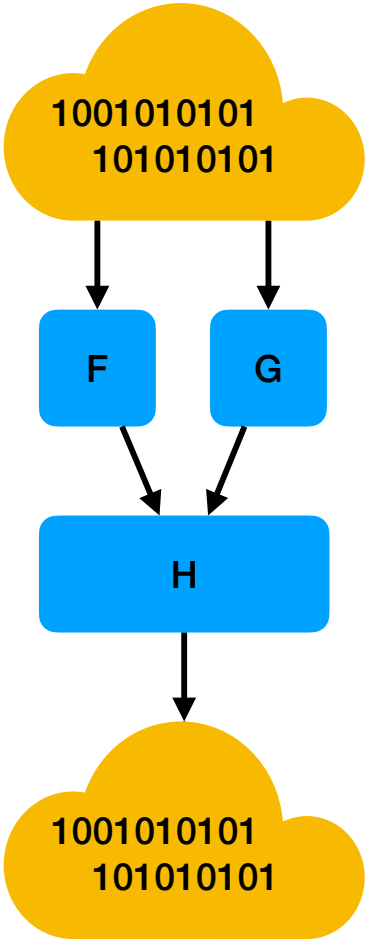


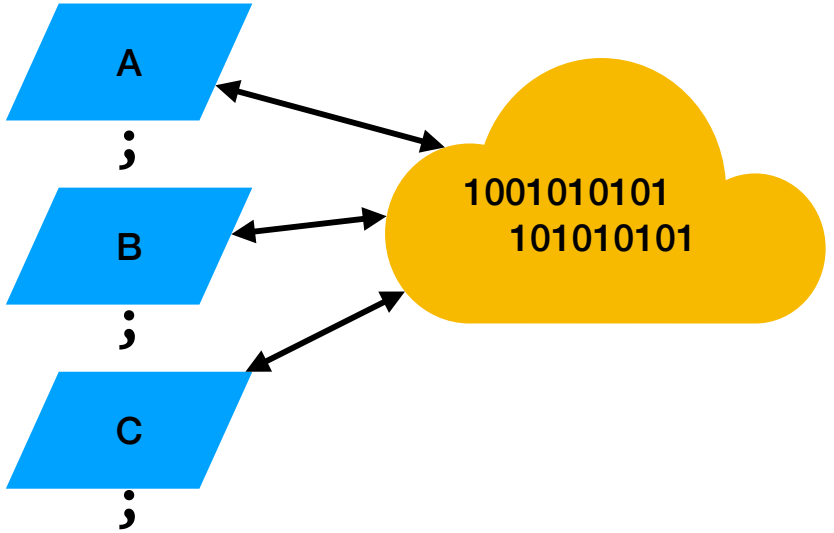
História e Bibliografia

- C (1972)
- K&R C (1978)
- ANSI C (1989)
- C99 (1999)
- C11 (2011)
- ...

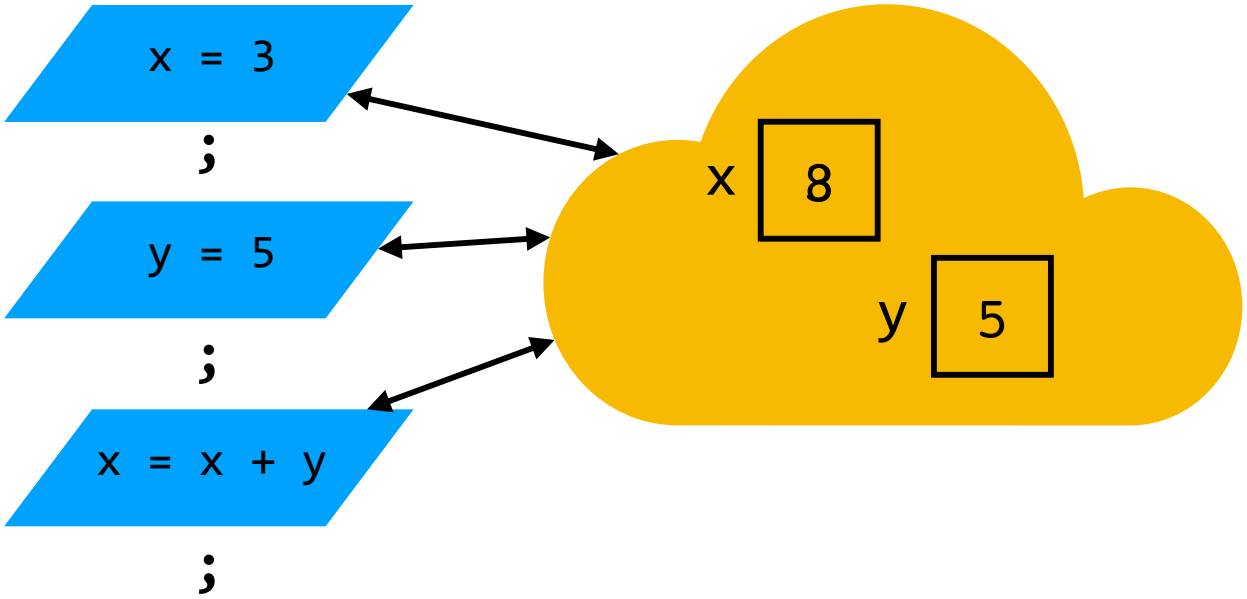


Funcional vs Imperativa





Variáveis e Atribuição



Programas

- Um *programa* C é uma sequência de declarações de *variáveis, tipos* ou *funções,* definições de funções*, e directivas de pré-processamento*
- Uma variável, tipo ou função só pode ser usada se declarada antes
- O espaçamento e indentação não têm significado
- As declarações são terminadas por ponto e vírgula
- Um programa pode estar dividido em vários ficheiros (*aka* módulos ou bibliotecas)
- A execução de um programa começa na função especial `main`

Declaração de variáveis

tipo id;

tipo id = expr;

tipo id_0, id_1, …;

tipo $id_0 = expr_0$, $id_1 = expr_0$, …;

Tipos numéricos

Tipo	Modificadores	Tamanho
`char`	**`signed`**, **`unsigned`**	≥ 1
`short`	**`signed`** (default), **`unsigned`**	≥ 2
`int`	**`signed`** (default), **`unsigned`**	≥ 2
`long`	**`signed`** (default), **`unsigned`**	≥ 4
`float`		precisão simples
`double`		precisão dupla

Aula 2

Funções

- A *declaração* de uma função inclui os tipos dos parâmetros e o tipo do valor retornado
- Uma função pode não ter parâmetros, nem retornar qualquer valor, usando-se neste caso o tipo especial **`void`** como tipo de retorno
- A declaração de uma função é normalmente seguida da respectiva *definição*, mas podem estar separadas
- A definição de uma função é uma sequência declarações (de variáveis ou tipos) e de *comandos* entre chavetas
- Tal como as declarações, os comandos são terminados por ponto e vírgula
- O comando **`return`** é usado para retornar um valor

Definição de funções

```
tipo id (tipo1 id1, …, tipon idn) {

   // declarações e comandos

   return expr;
}
```

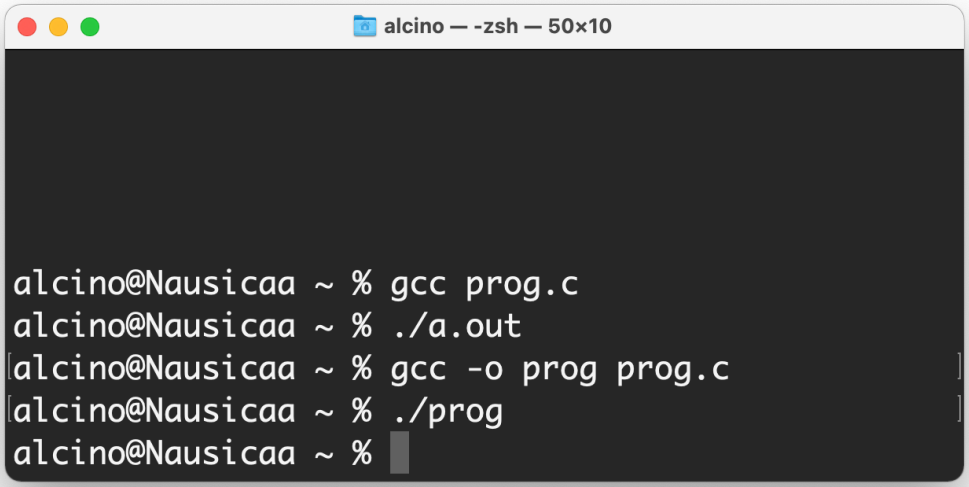
Exemplo

```
int dobro(int a) {
  int r;
  r = 2*a;
  return r;
}

int main() {
  int r;
  r = dobro(3);
  return 0;
}
```

Compilação

```c
int dobro(int a) {
  int r;
  r = 2*a;
  return r;
}

int main() {
  int r;
  r = dobro(3);
  return 0;
}
```

prog.c



Declaração vs Definição

```
int dobro(int);      // Declaração

int main() {
  int r;
  r = dobro(3);
  return 0;
}

int dobro(int a) {   // Definição
  int r;
  r = 2*a;
  return r;
}
```

Directiva #include

```c
int dobro(int a) {
  int r;
  r = 2*a;
  return r;
}
```

dobro.c

```c
#include "dobro.c"

int main() {
  int r;
  r = dobro(3);
  return 0;
}
```

prog.c

Bibliotecas pré-definidas

Nome	Conteúdo
`<stdio.h>`	Input e output
`<stdlib.h>`	Conversão de tipos, geração de números aleatórios, alocação de memória, …
`<math.h>`	Funções matemáticas (exponenciação, raíz quadrada, trigonométricas, …)
`<string.h>`	Manipulação de strings

A função `printf`

```c
#include <stdio.h>

int main() {
  printf("Olá mundo!\n");
  printf("O dobro de %s é %d.\n", "dois", 4);
  return 0;
}
```

Códigos de formatação

Código	Formatação
%d	Número inteiro em notação decimal com sinal
%x	Número inteiro em notação hexadecimal
%f	Número real em notação decimal
%e	Número real em notação científica
%c	Caracter
%s	String
%%	Caracter '%'

Códigos de formatação

Código	Formatação
`%nd`	Número inteiro em notação decimal com sinal, sendo *n* o número mínimo de caracteres a imprimir. Se o tamanho do número for menor são impressos espaços à esquerda.
`%.pf`	Número real em notação decimal, sendo *p* o número de dígitos à direita da vírgula
`%n.pf`	Idem, sendo *n* o número mínimo de caracteres a imprimir.

Comandos vs Expressões

- Os *comandos* afectam o estado do programa
  - Uma atribuição é um comando
- As *expressões* denotam um valor
  - Definidas à custa de variáveis, constantes, operadores e funções

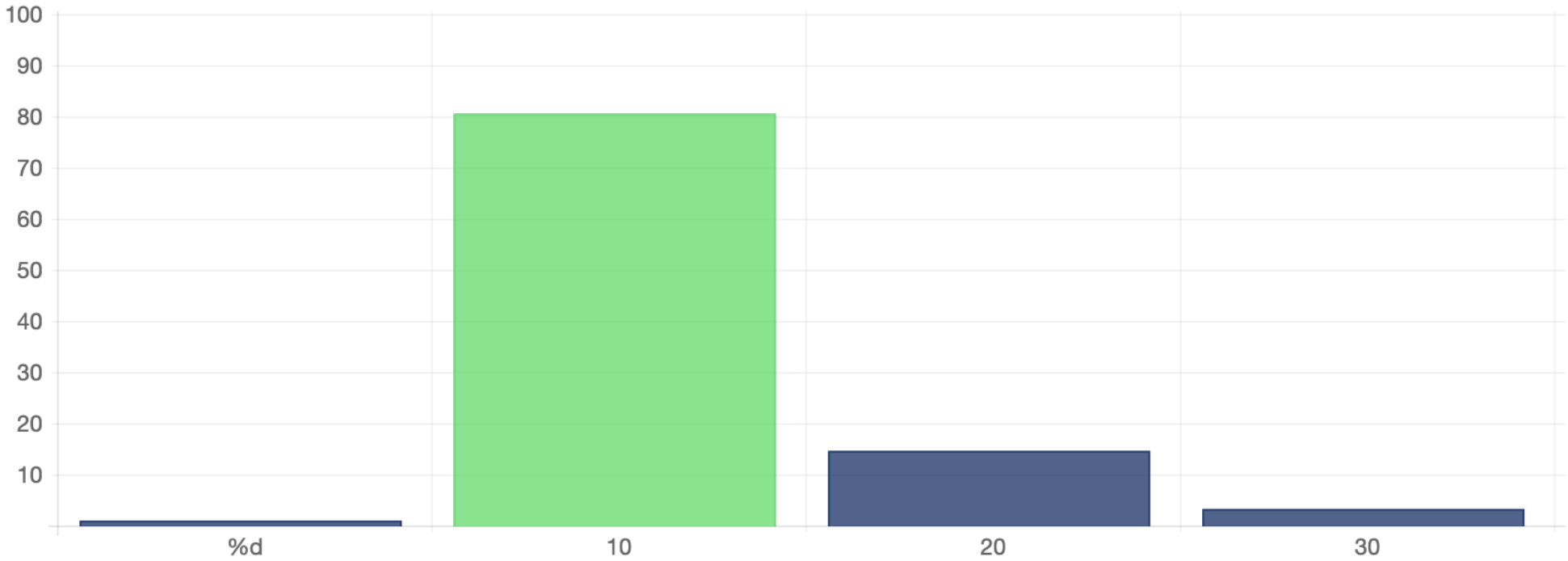
Expressões aritméticas

Operador	Significado
+	Adição
-	Subtração
*	Multiplicação
/	Divisão
%	Resto da divisão inteira

#1 Que imprime o seguinte programa?

```c
#include <stdio.h>

int main() {
  int x = 20, y = 10;
  x = x + y;
  y = x - y;
  x = x - y;
  printf("%d\n", x);
  return 0;
}
```

#1 Que imprime o seguinte programa?

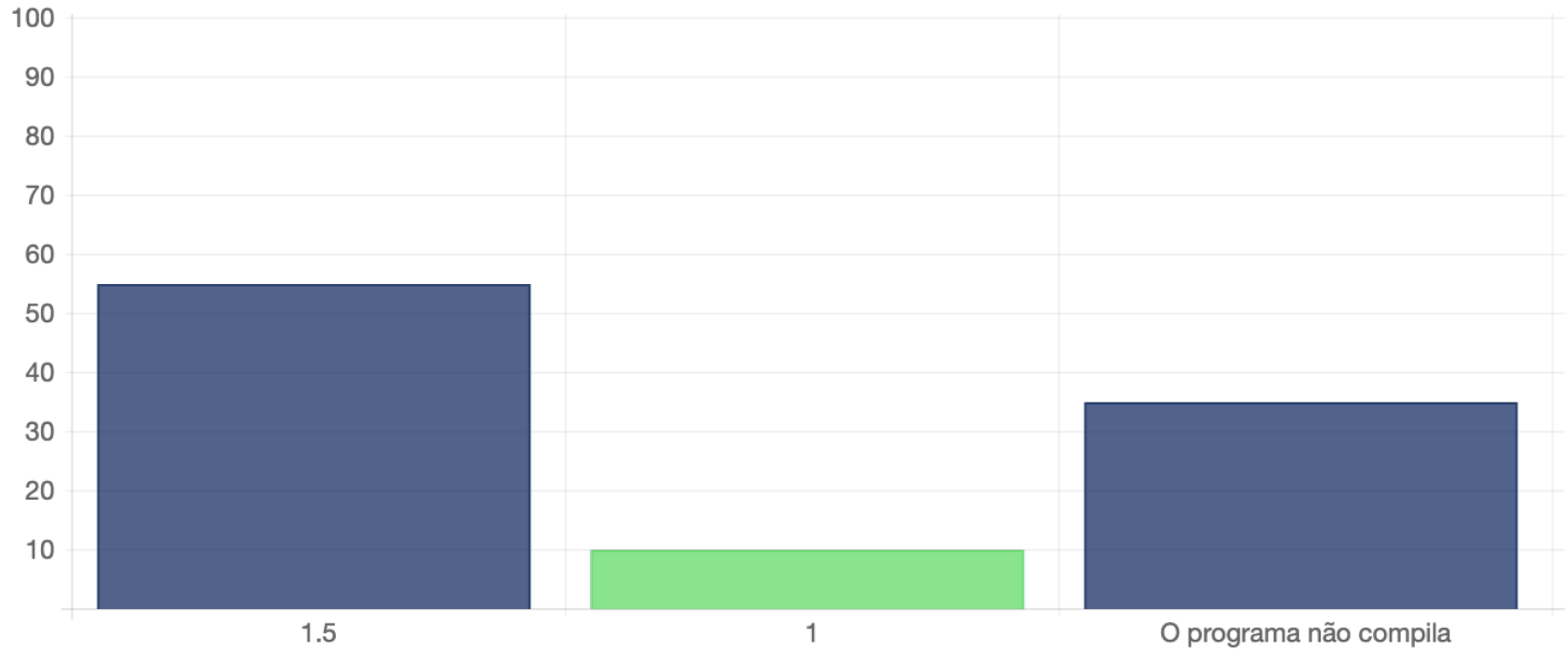


https://pythontutor.com/c.html

#2 Qual o valor de `f` depois da atribuição?

```c
int main() {
  float f;
  f = 3 / 2;
  return 0;
}
```

#2 Qual o valor de `f` depois da atribuição?



Conversões entre tipos

- Numa operação aritmética o operando de tipo “mais pequeno” é convertido para o tipo “maior”, sendo a operação realizada no tipo “maior”
  - Se um operando é um **`double`** o outro é convertido para **`double`**
  - Senão, se um operando é um **`float`** o outro é convertido para **`float`**
  - Senão, qualquer **`char`** ou **`short`** é promovido para **`int`**
  - Depois, se um operando é **`long`** o outro é convertido para **`long`**
- Numa atribuição numérica o valor da expressão é convertido implicitamente para o tipo da variável
  - Uma conversão pode também ser feita de forma explícita com o operador unário (*`tipo`*)

Conversões entre tipos

Divisão exacta

```c
int main() {
  float f;
  f = 3 / 2.0;
  return 0;
}
```

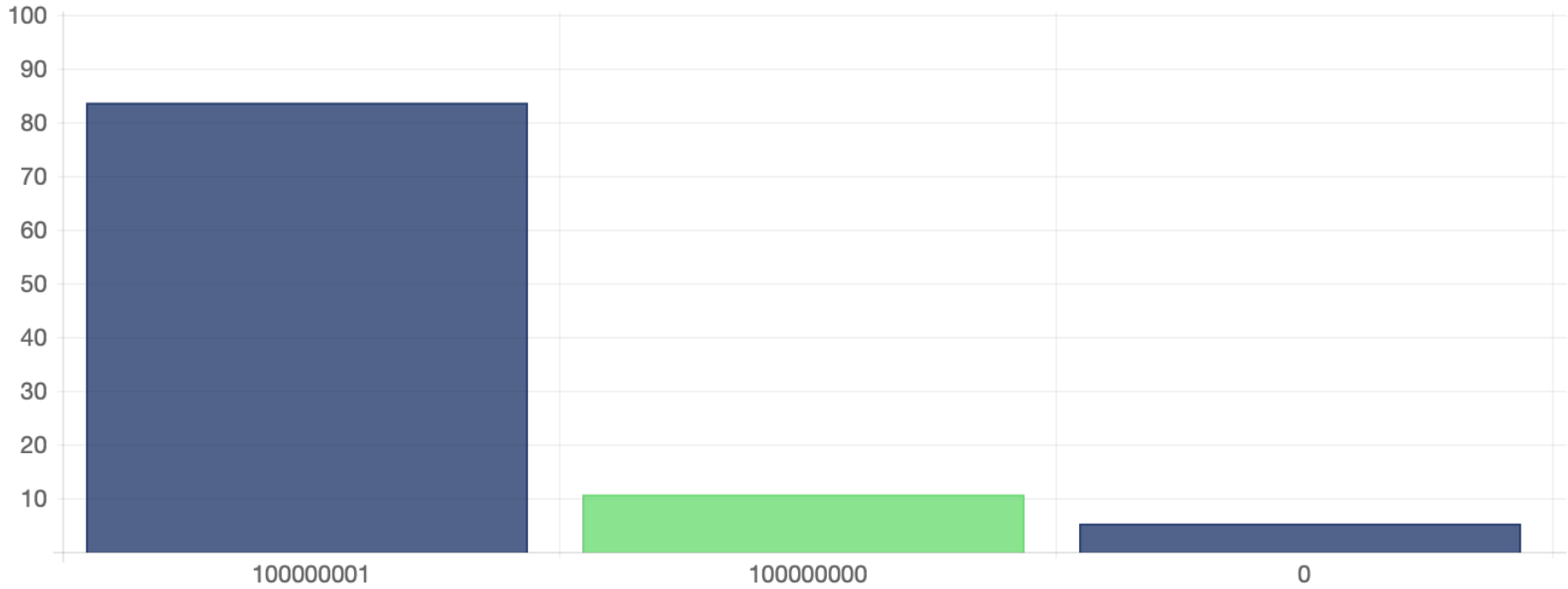
```c
int main() {
  float f;
  f = 3 / (float) 2;
  return 0;
}
```

Aula 3

#3 Qual o valor de x no final?

```
int main() {
  int x = 100000001;
  float f;
  f = x;
  x = f;
  return 0;
};
```

#3 Qual o valor de x no final?



Máximo

```c
#include <stdlib.h>

int max(int a, int b) {
  int r;
  r = (a + b + abs(a-b)) / 2;
  return r;
}
```

Condicional

if (*expr*) cmd_1; **else** cmd_2;

if (*expr*) *cmd*;

Operadores relacionais

Operador	Significado
==	Igualdade
!=	Diferença
<	Menor
<=	Menor ou igual
>	Maior
<=	Menor ou igual

Operadores lógicos

Operador	Significado
!	Negação
&&	Conjunção
||	Disjunção

Booleanos

- Não existe o tipo booleano em C
- Qualquer expressão numérica pode ser usada como booleano
  - O valor `0` corresponde a falso
  - Um valor diferente de `0` corresponde a verdadeiro
- Os operadores relacionais e lógicos devolvem `0` quando o resultado é falso e `1` quando é verdadeiro

Máximo

```
int max(int a, int b) {
  int r;
  if (a > b) r = a; else r = b;
  return r;
}
```

Máximo

```
int max(int a, int b) {
  if (a > b) return a;
  return b;
}
```

Blocos de comandos

- Em qualquer sítio onde é esperado um comando podemos colocar um *bloco de comandos*
- Um bloco de comandos é uma sequência de comandos ou declarações de variáveis entre chavetas
- As variáveis declaradas num bloco só podem ser usadas nesse bloco
- A definição de uma função é de facto um bloco de comandos

Máximo

```
int max(int a, int b) {
 if (a > b) {
    int r;
    r = a;
    return r;
  } else {
    int m;
    m = b;
    return m;
  }
}
```

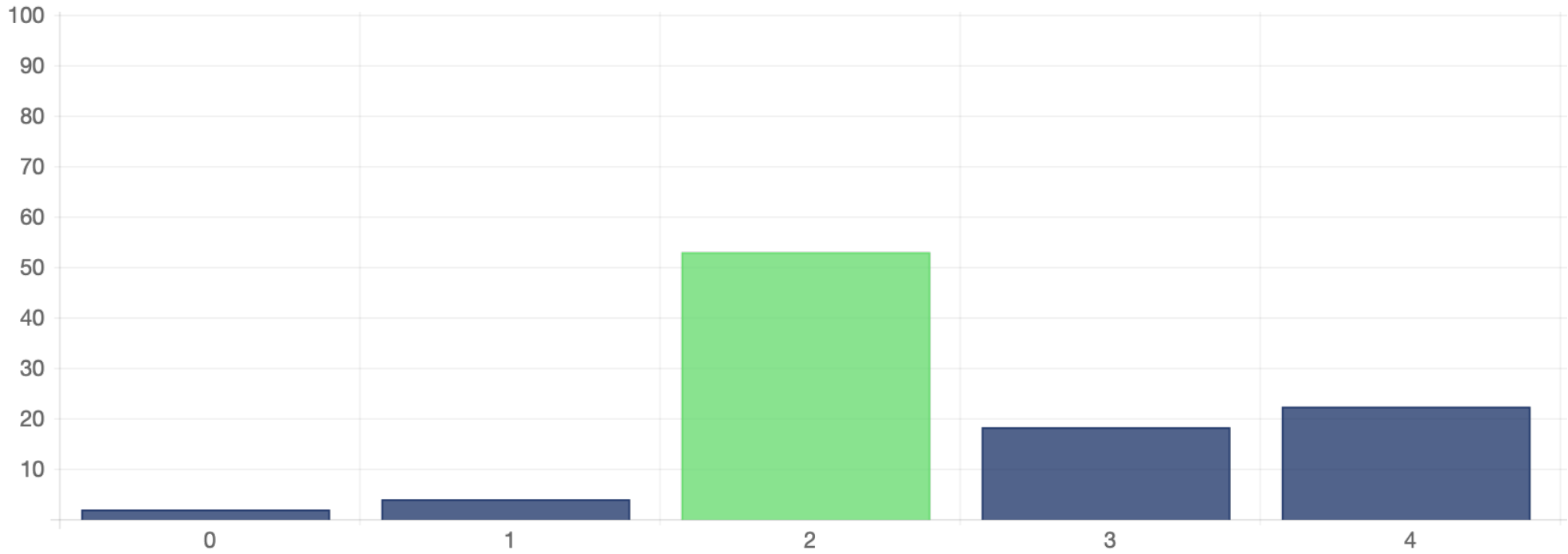
Expressões lógicas

- A avaliação de uma expressão lógica é feita da esquerda para a direita
- Termina logo que seja possível determinar o valor da expressão

#4 Quantas comparações faz `isalpha('0')`?

```
int isalpha(int c) {
  return ((c >= 'a' && c <= 'z') || (c >= 'A' && c <= 'Z'));
}
```

#4 Quantas comparações faz `isalpha('0')`?



Ciclo `while`

```
while (expr) cmd;
```

Factorial

```
int fact(int n) {
  int r = 1;
  int i = 1;
  while (i <= n) {
    r = r * i;
    i = i + 1;
  }
  return r;
}
```

Factorial

```
int fact(int n) {
  int r = 1;
  int i = 1;
  while (i <= n) {
    r = r * i;
    i = i + 1;
  }
  return r;
}
```

n	r	i	i <= n
5	1	1	1
5	1	2	1
5	2	3	1
5	6	4	1
5	24	5	1
5	120	6	0

Factorial

```
int fact(int n) {
  int r = 1;
  while (n > 0) {
    r = r * n;
    n = n - 1;
  }
  return r;
}
```

Factorial

```
int fact(int n) {
  int r = 1;
  while (n > 0) {
    r = r * n;
    n = n - 1;
  }
  return r;
}
```

n	r	n > 0
5	1	1
4	5	1
3	20	1
2	60	1
1	120	1
0	120	0

Operadores de atribuição

```
var = var op expr;
```

≡

```
var op= expr;
```

Factorial

```
int fact(int n) {
  int r = 1;
  int i = 1;
  while (i <= n) {
    r *= i;
    i += 1;
  }
  return r;
}
```

Comandos vs Expressões

- Em C qualquer expressão pode ser usada como um comando

```
int main() {
  3+4;
  return 0;
}
```

- O comando de atribuição é de facto uma expressão
  - O valor da atribuição é o valor da expressão atribuída
  - O efeito no estado é modificar o valor da variável

Operadores ++ e --

Expressão	Valor	Efeito
`++x`	`x + 1`	`x = x + 1`
`x++`	`x`	`x = x + 1`
`--x`	`x - 1`	`x = x - 1`
`x--`	`x`	`x = x - 1`

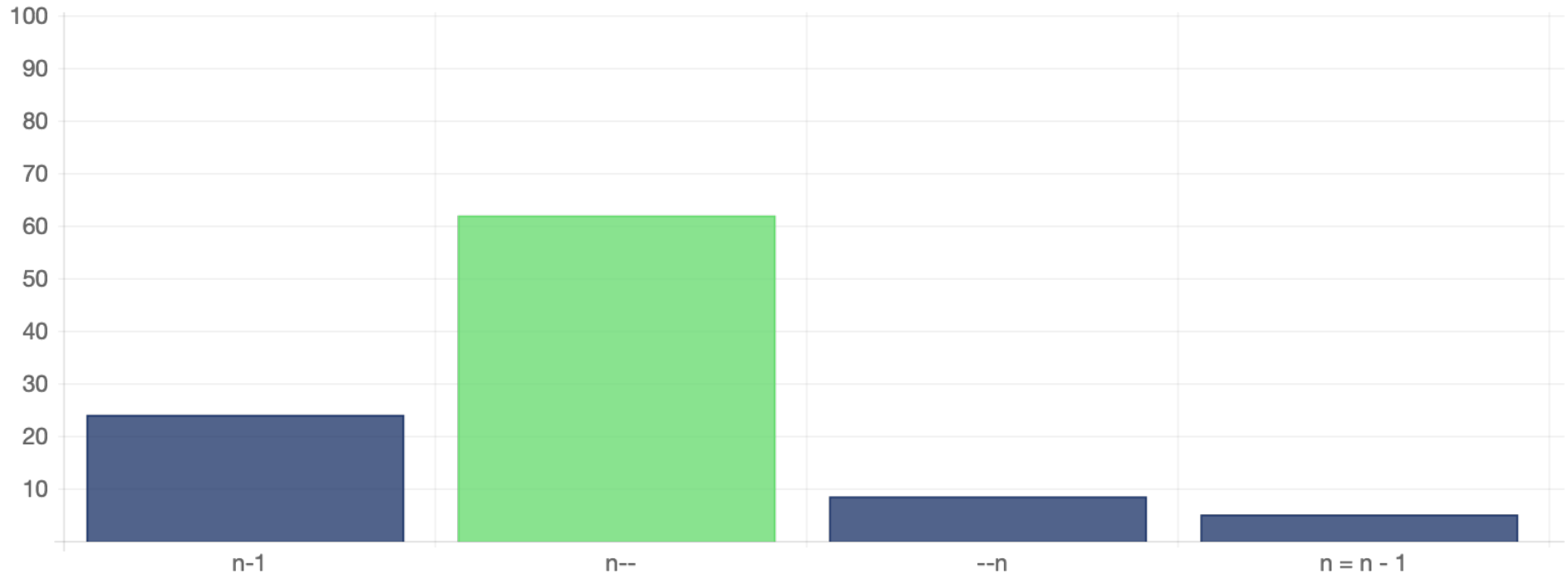
Factorial

```
int fact(int n) {
  int r, i;
  r = i = 1;
  while (i <= n) {
    r *= i;
    i++;
  }
  return r;
}
```

#5 Que expressão usar para calcular o factorial?

```
int fact(int n) {
  int r = 1;
  while (n > 0) r *=      ;
  return r;
}
```

#5 Que expressão usar para calcular o factorial?



Factorial

```
int fact(int n) {
  int r = 1;
  while (n -= (r *= n) > 0);
  return r;
}
```

Aula 4

Ciclo `for`

```
init; while (cond) {cmd; iter;}
```

≡

```
for (init; cond; iter) cmd;
```

Factorial

```
int fact(int n) {
  int r = 1;
  int i = 1;
  while (i <= n) {
    r *= i;
    i++;
  }
  return r;
}
```

```
int fact(int n) {
  int r = 1;
  for (int i = 1; i <= n; i++)
    r *= i;
  return r;
}
```

Factorial

```
int fact(int n) {
  int r = 1;
  while (n > 0) {
    r *= n;
    n--;
  }
  return r;
}
```

```
int fact(int n) {
  int r;
  for (r = 1; n > 0; n--)
    r *= n;
  return r;
}
```

Factorial

```
int fact(int n) {
  int r;
  for (r = 1; n > 0; r *= n, n--);
  return r;
}
```

Ciclo `do-while`

```
cmd; while (cond) cmd;
```

≡

```
do cmd; while (cond);
```

Factorial

```
int fact(int n) {
  int r = 1, i = 0;
  do {
    i++;
    r *= i;
  }
  while (i < n);
  return r;
}
```

`break` e `continue`

- O comando **`break`** termina a execução de um ciclo
  - A execução continua no primeiro comando depois do ciclo
- O comando **`continue`** termina a iteração actual
  - Num ciclo **`while`** ou **`do-while`** a execução continua no teste
  - Num ciclo **`for`** a execução continua no comando de incremento

Sorteio

```c
#include <stdio.h>
#include <stdlib.h>

int main() {
  int r;
  while (1) {
    r = rand();                 // "sortear" um número entre 0 e RAND_MAX
    if (r == 0) break;
    if (r > 100) continue;
    printf("%d\n",r);
  }
  return 0;
}
```

Sorteio

```c
#include <stdio.h>
#include <stdlib.h>

int main() {
  int r;
  while (1) {
    r = rand();                 // "sortear" um número entre 0 e RAND_MAX
    if (r == 0) break;
    if (r <= 100)
      printf("%d\n",r);
  }
  return 0;
}
```

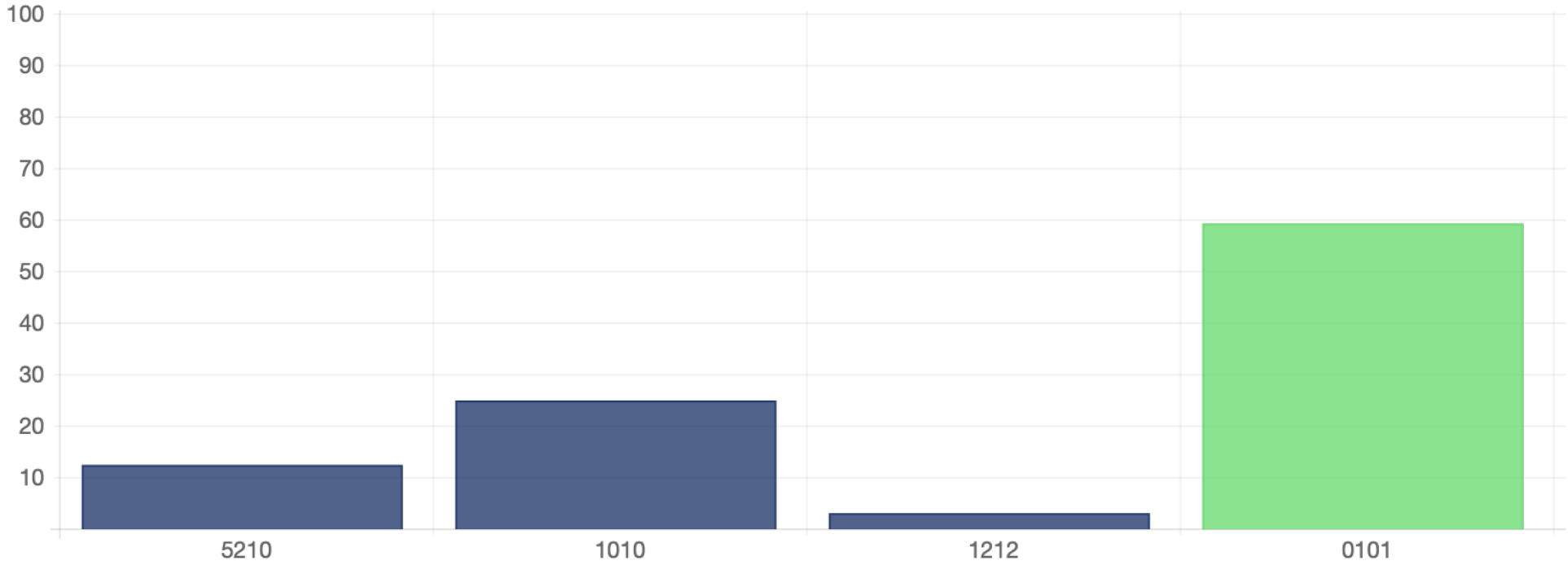
Sorteio

```c
#include <stdio.h>
#include <stdlib.h>

int main() {
  int r, ok = 1;
  while (ok) {
    r = rand();                 // "sortear" um número entre 0 e RAND_MAX
    if (r == 0) ok = 0;
    if (ok && r <= 100)
      printf("%d\n",r);
 }
  return 0;
}
```

#6 Que imprime `proc(10)`?

```
void proc(unsigned int n) {
  for (; n > 0; n /= 2) printf("%d", n % 2);
}
```

#6 Que imprime `proc(10)`?



Imprimir binário

```
int size(unsigned int n) {
  int size = 0;
  for (; n > 0; n /= 2) size++;
  return size;
}
int bit(unsigned int n, int i) {
  for (; i > 0; i--) n /= 2;
  return n % 2;
}
void binary(unsigned int n) {
  for (int i = size(n)-1; i >= 0; i--) {
    printf("%d", bit(n, i));
  }
}
```

Operadores lógicos *bitwise*

Operador	Significado	Exemplo (`unsigned char`)
`~`	Negação	`~10101001 == 01010110`
`&`	Conjunção	`10101001 & 11001010 == 10001000`
`|`	Disjunção	`10101001 | 11001010 == 11101011`
`^`	Disjunção exclusiva	`10101001 ^ 11001010 == 01100011`
`>>`	Shift para a direita	`10101001 >> 3 == 00010101`
`<<`	Shift para a esquerda	`10101001 << 3 == 01001000`

Imprimir binário

```
int size(unsigned int n) {
  int size = 0;
  for (; n > 0; n >>= 1) size++;
  return size;
}
int bit(unsigned int n, int i) {
  return (n >> i) & 1;
}
void binary(unsigned int n) {
  for (int i = size(n)-1; i >= 0; i--) {
    printf("%d", bit(n, i));
  }
}
```

Recursividade

- Uma função pode invocar-se a si própria directa ou indirectamente

Factorial

```
int fact(int n) {
  int r;
  if (n > 0) r = n * fact(n-1);
  else r = 1;
  return r;
}
```

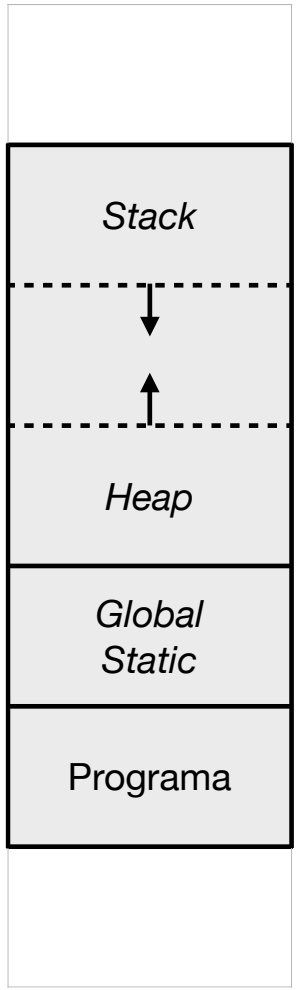
Imprimir binário

```
void binary(int n) {
  if (n > 0) {
    binary(n >> 1);
    printf("%d", n & 1);
  }
}
```

Aula 5

Gestão de memória

- Automática
  - Memória reservada e libertada automaticamente na *stack* durante a execução
  - Variáveis locais e parâmetros
- Dinâmica
  - Memória reservada e libertada explicitamente na *heap* durante a execução
- Estática
  - Memória reservada em tempo de compilação e libertada apenas quando o programa termina
  - Variáveis globais e **`static`**

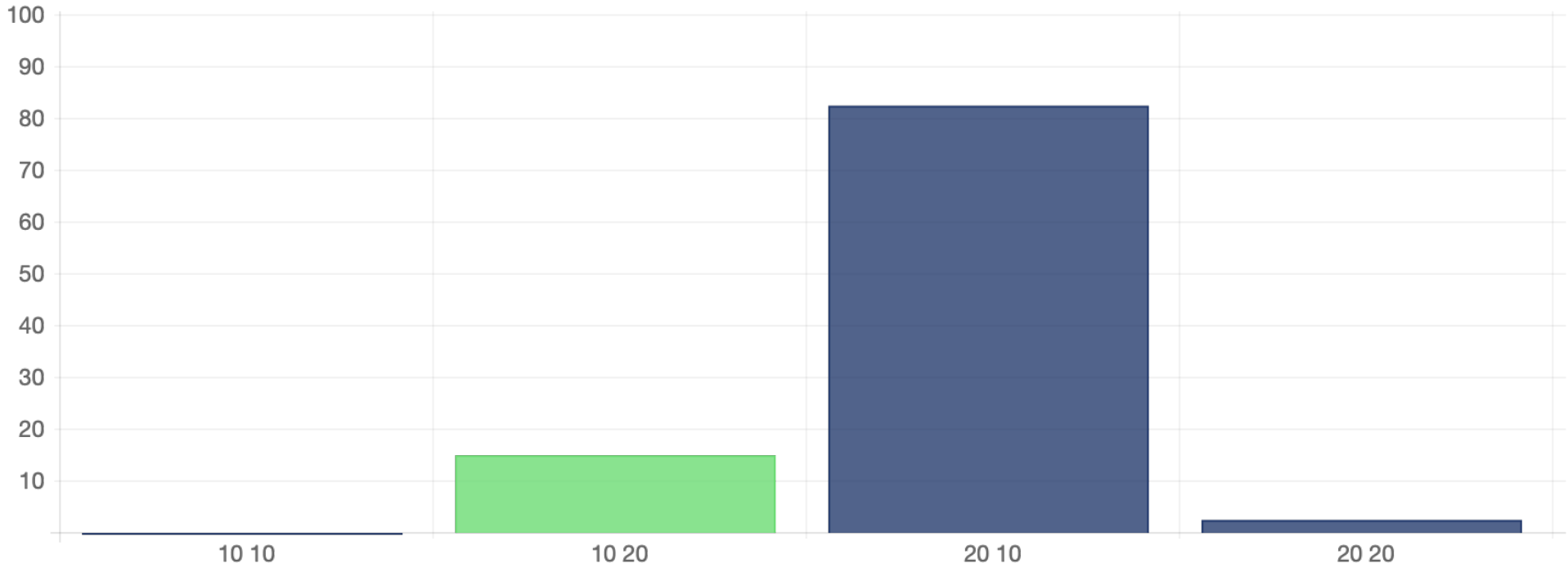


https://pythontutor.com/c.html

#7 Que imprime o seguinte programa?

```c
#include <stdio.h>

void swap(int x, int y) {
  int aux = y;
  y = x;
  x = aux;
}

int main() {
  int x = 10, y = 20;
  swap(x,y);
  printf("%d %d\n",x,y);
  return 0;
}
```

#7 Que imprime o seguinte programa?



Passagem de argumentos

- Passagem por valor (*call by value*)
  - O valor dos argumentos é copiado para os parâmetros da função
  - Uma modificação num parâmetro não afecta o argumento
- Passagem por referência (*call by reference*)
  - Uma referência (*alias*) para os argumentos é copiada para os parâmetros da função
  - Uma modificação num parâmetro afecta o argumento

Passagem de argumentos em C

- Em C temos sempre passagem por valor
- A passagem por referência pode ser simulada passando explicitamente (por valor) o endereço de memória do argumento
- Sabendo o endereço do argumento é possível na função alterar o seu conteúdo
- O endereço de uma variável é também conhecido como um *apontador* para a variável

Declaração de apontadores

tipo ***id**;

tipo ***id**$_0$, ***id**$_1$, …;

void ***id**;

Operadores de referência

Operador	Significado
`*expr`	Conteúdo do endereço *`expr`*
`&var`	Endereço de *`var`*

Swap

```c
#include <stdio.h>

void swap(int *x, int *y) {
  int aux = *y;
  *y = *x;
  *x = aux;
}

int main() {
  int x = 10, y = 20;
  swap(&x,&y);
  printf("%d %d\n",x,y);
  return 0;
}
```

Swap

```c
#include <stdio.h>

void swap(int *x, int *y) {
  int aux = *y;
  *y = *x;
  *x = aux;
}

int main() {
  int x = 10, y = 20;
  swap(&x,&y);
  printf("%d %d\n",x,y);
  return 0;
}
```

Endereço	Conteúdo	Variável	Função
16B8637E8	10	x	main
16B8637E4	20	y	

Swap

```c
#include <stdio.h>

void swap(int *x, int *y) {
  int aux = *y;
  *y = *x;
  *x = aux;
}

int main() {
  int x = 10, y = 20;
  swap(&x,&y);
  printf("%d %d\n",x,y);
  return 0;
}
```

Endereço	Conteúdo	Variável	Função
16B8637E8	10	x	main
16B8637E4	20	y	
16B8637A4	16B8637E8	x	swap
16B8637A0	16B8637E4	y	
16B86379C	?	aux	

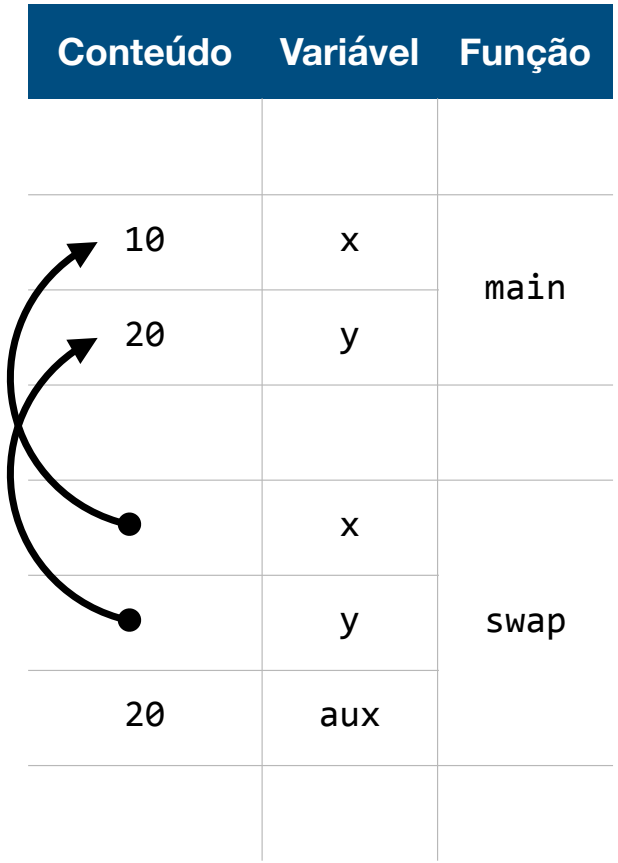
Swap

```c
#include <stdio.h>

void swap(int *x, int *y) {
  int aux = *y;
  *y = *x;
  *x = aux;
}

int main() {
  int x = 10, y = 20;
  swap(&x,&y);
  printf("%d %d\n",x,y);
  return 0;
}
```

Conteúdo	Variável	Função
10	x	main
20	y	
	x	swap
	y	
?	aux	

Swap

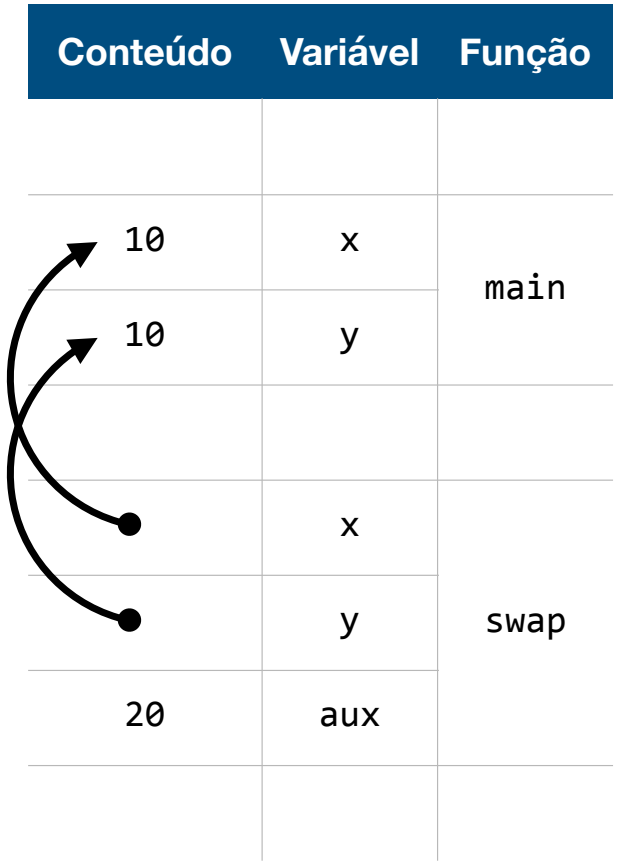
```c
#include <stdio.h>

void swap(int *x, int *y) {
  int aux = *y;
  *y = *x;
  *x = aux;
}

int main() {
  int x = 10, y = 20;
  swap(&x,&y);
  printf("%d %d\n",x,y);
  return 0;
}
```



Conteúdo	Variável	Função
10	x	main
20	y	
	x	swap
	y	
20	aux	

Swap

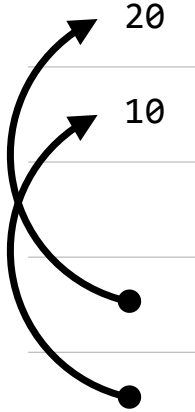
```c
#include <stdio.h>

void swap(int *x, int *y) {
  int aux = *y;
  *y = *x;
  *x = aux;
}

int main() {
  int x = 10, y = 20;
  swap(&x,&y);
  printf("%d %d\n",x,y);
  return 0;
}
```



Conteúdo	Variável	Função
10	x	main
10	y	
	x	swap
	y	
20	aux	

Swap

```c
#include <stdio.h>

void swap(int *x, int *y) {
  int aux = *y;
  *y = *x;
  *x = aux;
}

int main() {
  int x = 10, y = 20;
  swap(&x,&y);
  printf("%d %d\n",x,y);
  return 0;
}
```



Conteúdo	Variável	Função
20	x	main
10	y	
	x	swap
	y	
20	aux	

Swap

```c
#include <stdio.h>

void swap(int *x, int *y) {
  int aux = *y;
  *y = *x;
  *x = aux;
}

int main() {
  int x = 10, y = 20;
  swap(&x,&y);
  printf("%d %d\n",x,y);
  return 0;
}
```

Conteúdo	Variável	Função
20	x	main
10	y	

A função `scanf`

```c
#include <stdio.h>

int fact(int n) {
  int r = 1;
  for (; n > 0; n--) r *= n;
  return r;
}

int main() {
  int x;
  if (scanf("%d", &x) != 1) return 1;
  printf("fact(%d) == %d\n", x, fact(x));
  return 0;
}
```

Aula 6

Contar caracteres

```c
#include <stdio.h>

int main() {
  int n = 0;
  char c;
  while ((c = getchar()) != '\n') n++;
  printf("%d\n", n);
  return 0;
}
```

#8 Como contar dígitos?

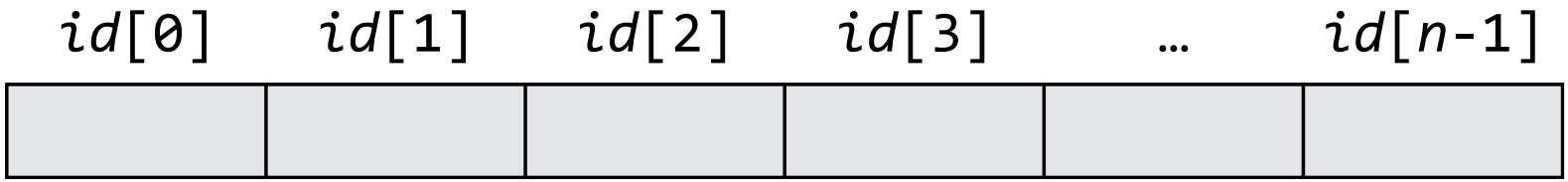
```c
#include <stdio.h>

int main() {
  int n = 0;
  char c;
  while ((c = getchar()) != '\n') {                    }
  printf("%d\n", n);
  return 0;
}
```

Contar dígitos separadamente

```c
#include <stdio.h>

int main() {
  int n0 = 0, n1 = 0, …;
  char c;
  while ((c = getchar()) != '\n') {
    n0 += (c == '0');
    n1 += (c == '1');
    …
  }
  printf("0: %d\n", n0);
  printf("1: %d\n", n1);
  …
  return 0;
}
```

Declaração de arrays

tipo id[*n*];

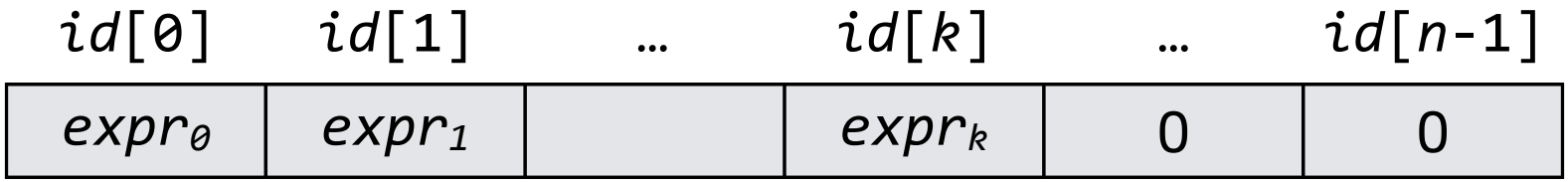


Contar dígitos separadamente

```c
#include <stdio.h>

int main() {
  int n[10], i;
  char c;
  for (i = 0; i < 10; i++) n[i] = 0;
  while ((c = getchar()) != '\n')
    if (c >= '0' && c <= '9') n[c-'0']++;
  for (i = 0; i < 10; i++) printf("%d: %d\n", i, n[i]);
  return 0;
}
```

Inicialização de arrays

tipo id[*n*] = {*expr*$_0$, *expr*$_1$, …, *expr*$_k$};



Contar dígitos separadamente

```c
#include <stdio.h>

int main() {
  int n[10] = {0}, i;
  char c;
  while ((c = getchar()) != '\n')
    if (c >= '0' && c <= '9') n[c-'0']++;
  for (i = 0; i < 10; i++) printf("%d: %d\n", i, n[i]);
  return 0;
}
```

Directiva `#define`

`#define` *id expr*

`#define` *id*$(id_1, \ldots, id_n)$ *expr*

Sortear N inteiros diferentes

```c
#include <stdio.h>
#include <stdlib.h>

#define N 10

int existe(int x, int a[N], int n) {
  for (int i = 0; i < n; i++)
    if (a[i] == x) return 1;
  return 0;
}
```

```c
int main() {
  int i = 0, x, p[N];
  while (i < N) {
    x = rand();
    if (existe(x,p,i)) continue;
    printf("%d\n", x);
    p[i++] = x;
  }
  return 0;
}
```

Aula 7

Aritmética de apontadores

- Quando se adiciona ou subtrai uma constante a um apontador, o tamanho do valor apontado é tido em consideração

```
a = &v;
```

```
a + n == (char *) a + n*sizeof(v)
```

Arrays vs Apontadores

- O nome de um array corresponde ao endereço da primeira célula

```
a == &(a[0])
```

  - Quando é passado um array a uma função como argumento é de facto passado um apontador para a primeira célula

- O acesso a uma posição de um array é equivalente à deferência de um apontador

```
a[i] == *(a+i)
```

  - Alterações ao array dentro da função afetam o array argumento
  - O tamanho do array no parâmetro é irrelevante
  - Se for necessário, o tamanho tem que ser passado num argumento

Pesquisa

```
int existe(int x, int a[], int n) {
  for (int i = 0; i < n; i++)
    if (a[i] == x) return 1;
  return 0;
}
```

Pesquisa

```
int existe(int x, int *a, int n) {
  for (int i = 0; i < n; i++)
    if (*(a+i) == x) return 1;
  return 0;
}
```

Pesquisa

```
int existe(int x, int *a, int n) {
  for (int i = 0; i < n; i++, a++)
    if (*a == x) return 1;
  return 0;
}
```

Pesquisa

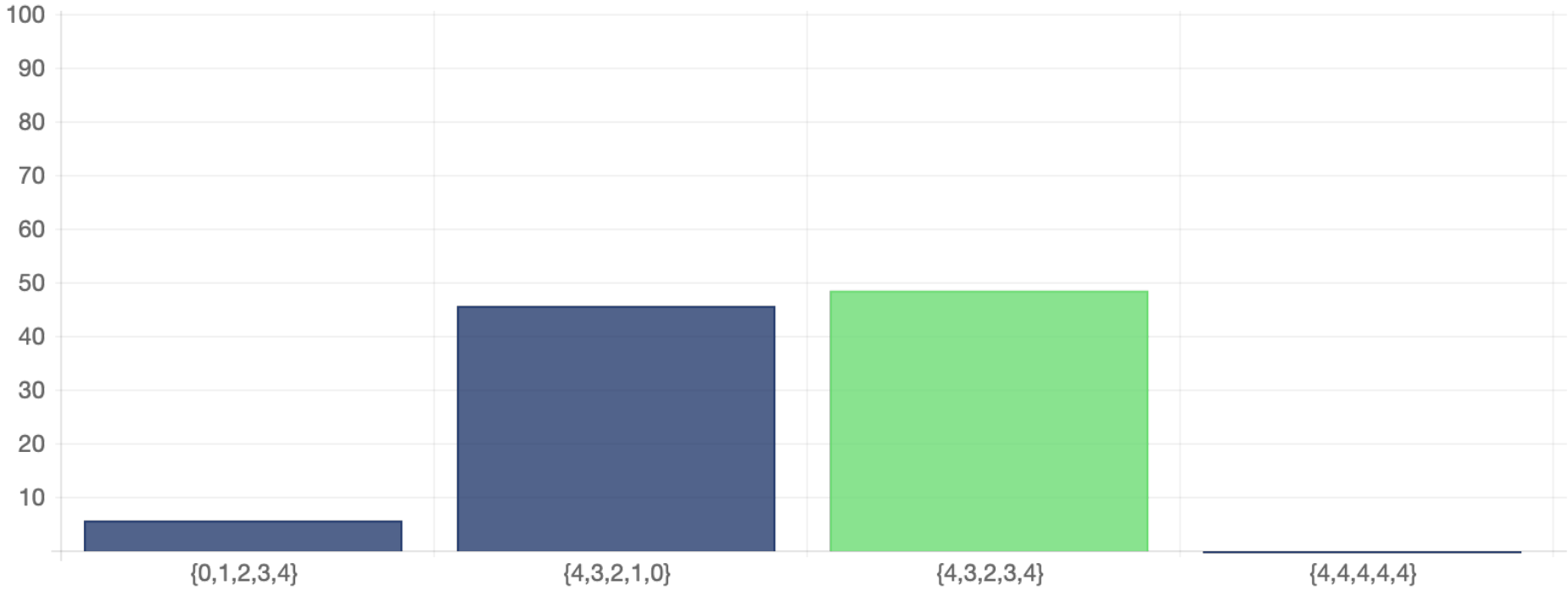
```c
int existe(int x, int *a, int n) {
  if (n == 0) return 0;
  if (*a == x) return 1;
  return existe(x, a+1, n-1);
}
```

https://pythontutor.com/c.html

#9 Qual o conteúdo de `a` depois do `modifica(a,5)`?

```
void modifica(int b[], int n) {
  int i = 0, j = n-1;
  while (i < n) {
    b[i] = b[j];
    i++; j--;
  }
}

int main() {
  int a[5] = {0,1,2,3,4};
  modifica(a,5);
  return 0;
}
```

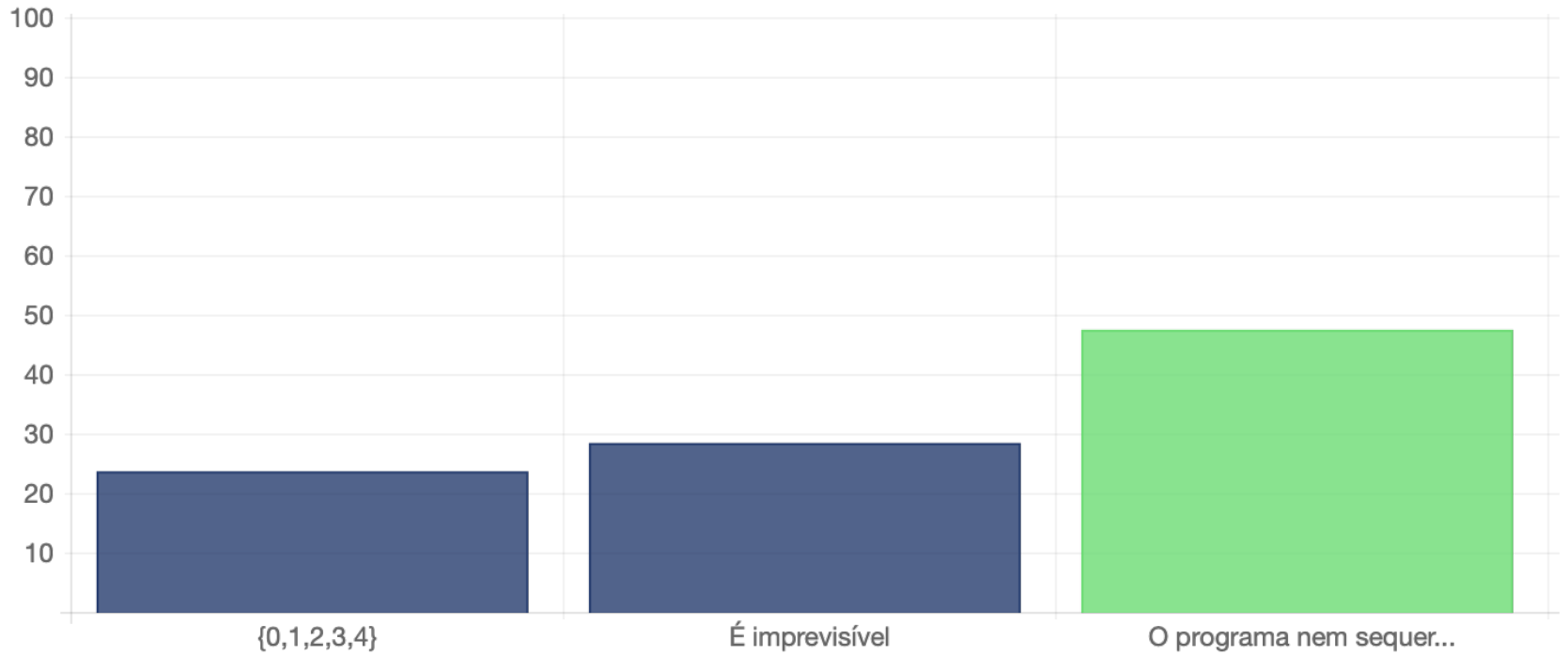
#9 Qual o conteúdo de `a` depois do `modifica(a,5)`?



#10 Qual o conteúdo de `b` depois do `copia(a,5)`?

```
int *copia(int a[], int n) {
  int b[n];
  for (int i = 0; i < n; i++) b[i] = a[i];
  return b;
}

int main() {
  int a[5] = {0,1,2,3,4};
  int b[5];
  b = copia(a,5);
  return 0;
}
```

#10 Qual o conteúdo de `b` depois do `copia(a,5)`?



Arrays vs Apontadores

- Na declaração de um parâmetro de uma função, `int v[N]` é a mesma coisa que `int *v`

  - Na stack é alocada 1 célula de memória para v com capacidade para um endereço

  - Dado um `0 <= i < N`, podemos modificar `v[i]` (modifica a `i`-ésima célula do array argumento)

  - Podemos modificar v (modifica a cópia local do endereço do array argumento)

Arrays vs Apontadores

- Mas na declaração de uma variável não é a mesma coisa!
- A declaração `int v[N]` aloca `N` células de memória, cada uma com capacidade para um `int`
  - Embora `v == &(v[0])`, não é alocada memória para `v`
  - Dado um `0 <= i < N`, podemos modificar `v[i]`, mas não é possível modificar `v`
- A declaração `int *v` aloca 1 célula de memória com capacidade para um endereço
  - Podemos modificar `v`
  - Mas não faz sentido modificar `v[i]`, a não ser que `v` aponte para um array

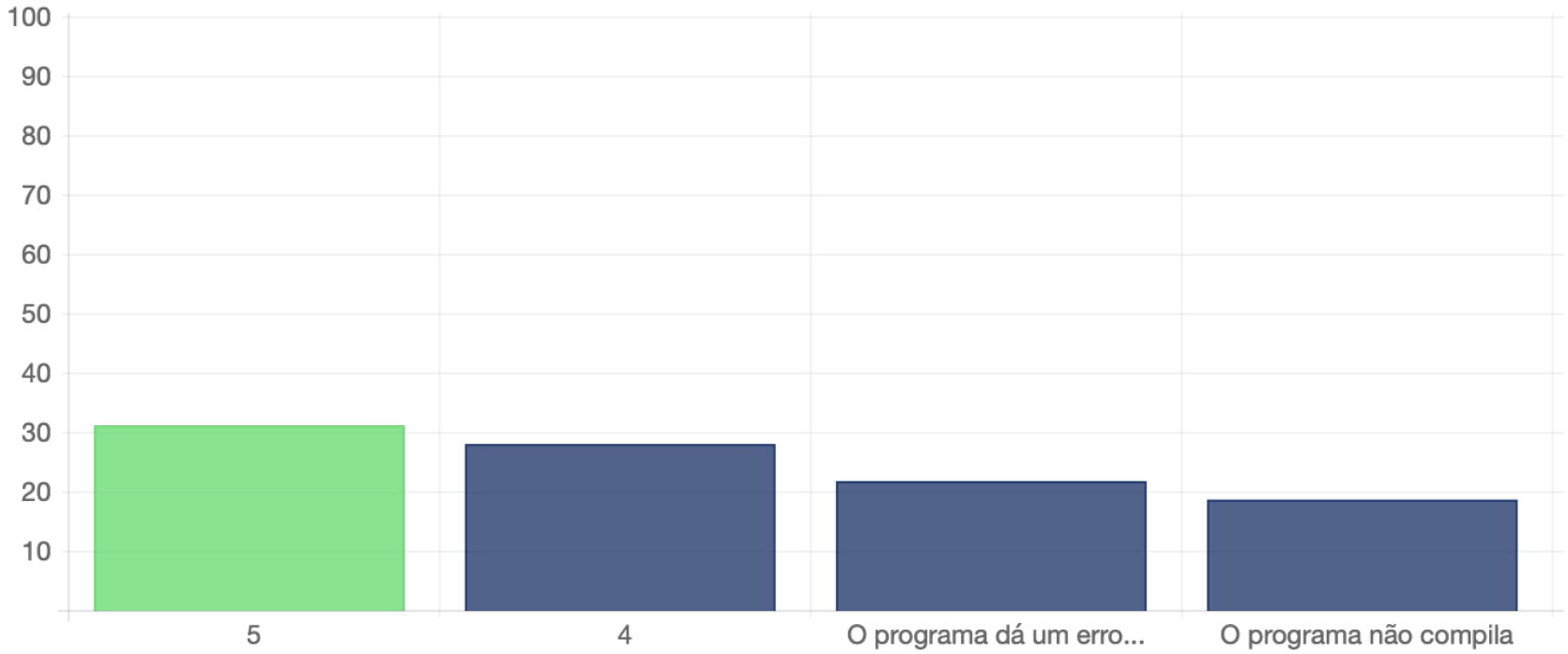
Copiar um array

```
void copia(int a[], int b[], int n) {
  for (int i = 0; i < n; i++) b[i] = a[i];
}

int main() {
  int a[5] = {0,1,2,3,4};
  int b[5];
  copia(a,b,5);
  return 0;
}
```

#11 Qual o conteúdo de `a[4]` no final?

```
int main() {
  int a[5] = {0,1,2,3,4};
  int *b = a;
  b[4] = 5;
  return 0;
}
```

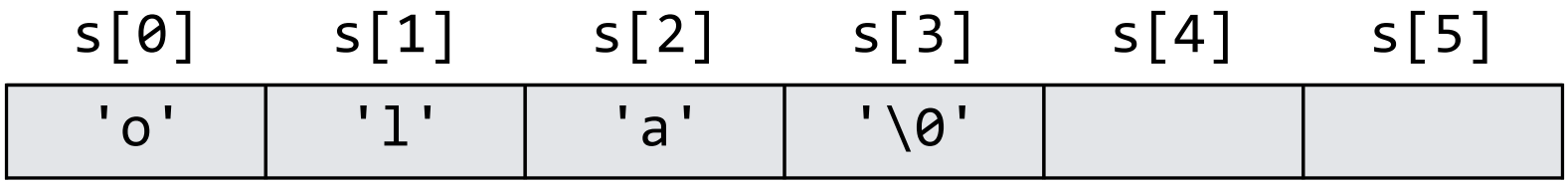
#11 Qual o conteúdo de `a[4]` no final?



Strings

- Uma string é um array de caracteres
- Para ser bem formada deve terminar com o caracter `'\0'`

```
char s[6] = "ola";
```



strlen

```
int strlen(char s[]) {
  int i;
  for (i = 0; s[i] != '\0'; i++);
  return i;
}
```

Aula 8

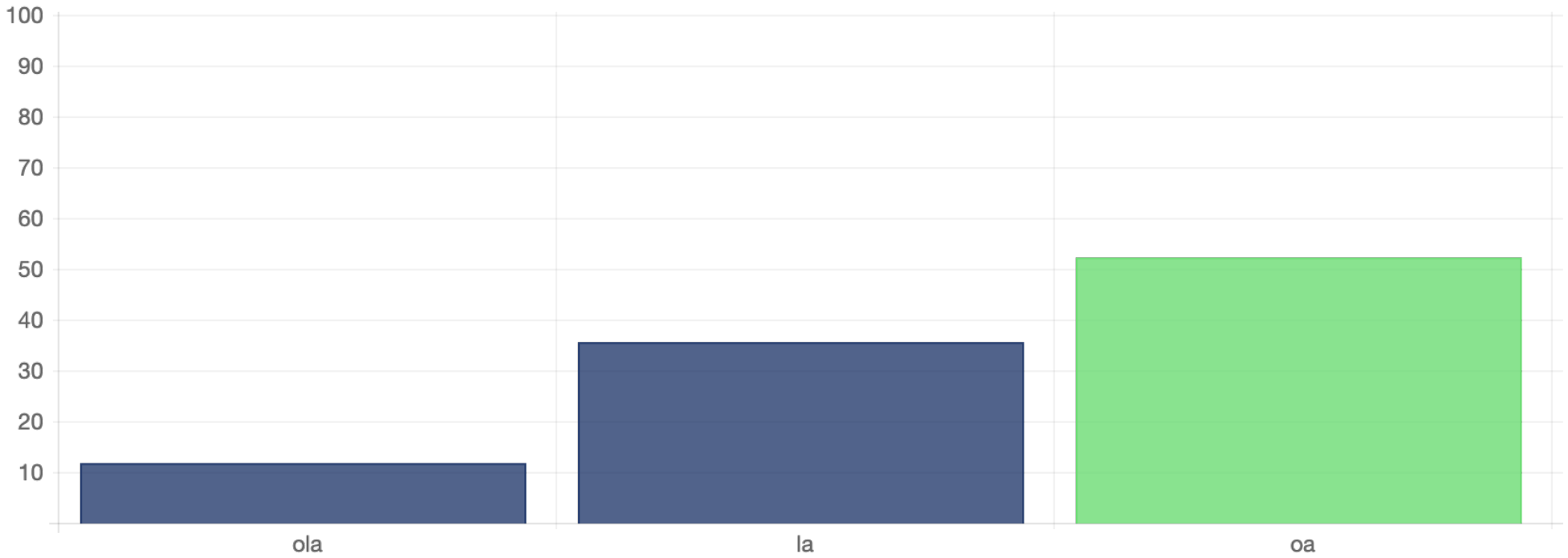
strlen

```
int strlen(char *s) {
  char *t = s;
  for (; *t; t++);
  return t-s;
}
```

#12 Que imprime o seguinte programa?

```
void func(char s[], int i) {
  for (; s[i] != '\0'; i++) s[i] = s[i+1];
}

int main() {
  char s[10] = "ola";
  func(s,1);
  printf("%s\n", s);
  return 0;
}
```

#12 Que imprime o seguinte programa?



Remover i-ésimo caracter

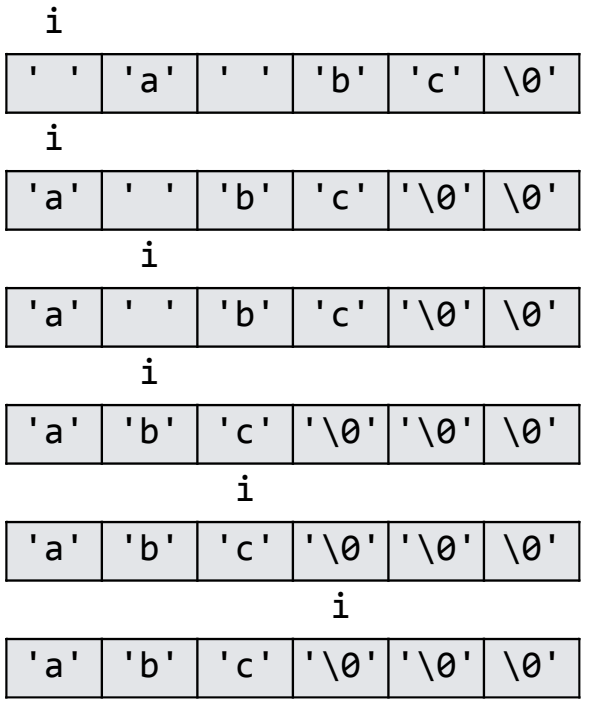
```
void delete(char s[], int i) {
  for (; s[i] != '\0'; i++) s[i] = s[i+1];
}

int main() {
  char s[10] = "ola";
  delete(s,1);
  printf("%s\n", s);
  return 0;
}
```

Remover i-ésimo caracter

```
char *delete(char s[], int i) {
  for (; s[i] != '\0'; i++) s[i] = s[i+1];
  return s;
}

int main() {
  char s[10] = "ola";
  printf("%s\n", delete(s,1));
  return 0;
}
```

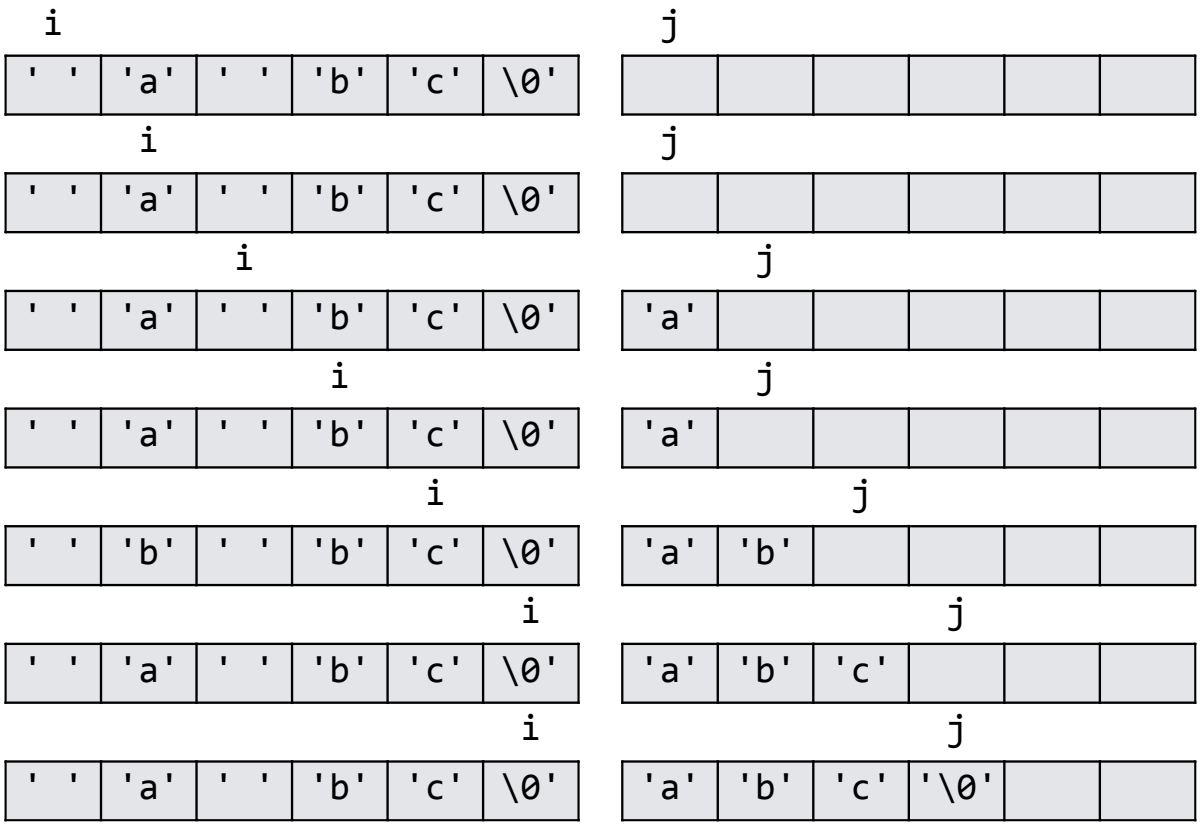
Remover espaços

```
#include <ctype.h>

char *trim(char s[]) {
  int i = 0;
  while (s[i] != '\0') {
    if (isspace(s[i])) delete(s,i);
    else i++;
  }
  return s;
}
```



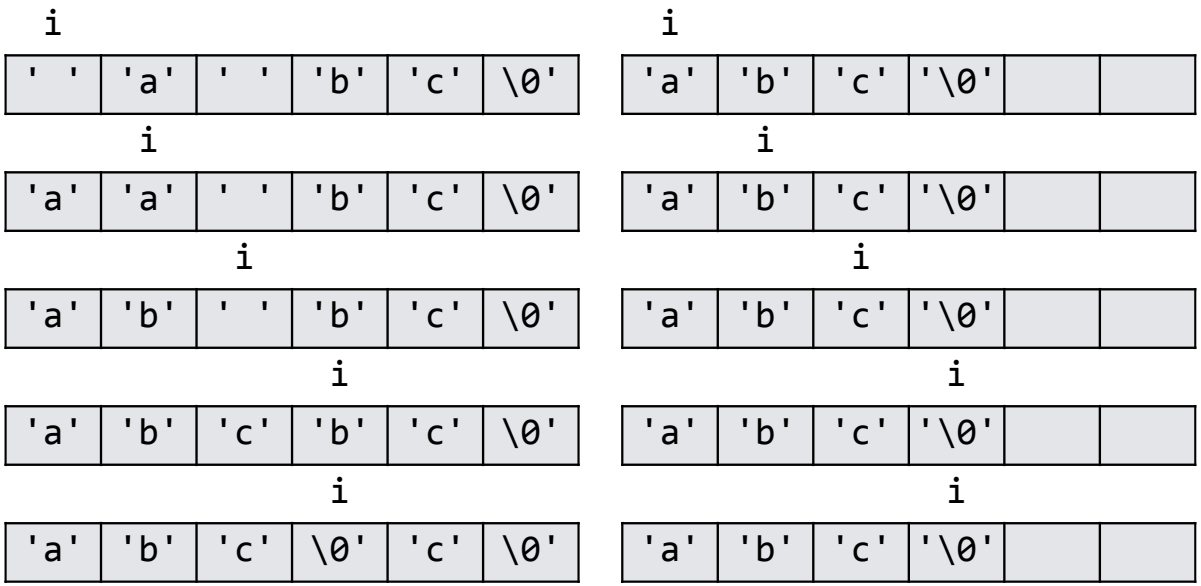
Remover espaços

```c
#include <ctype.h>

char *trim(char s[]) {
  int i, j = 0;
  char t[strlen(s)+1];
  for (i = 0; s[i] != '\0'; i++)
    if (!isspace(s[i])) {
      t[j] = s[i]; j++;
    }
  t[j] = '\0';
  for (i = 0; t[i] != '\0'; i++)
    s[i] = t[i];
  s[i] = '\0';
  return s;
}
```



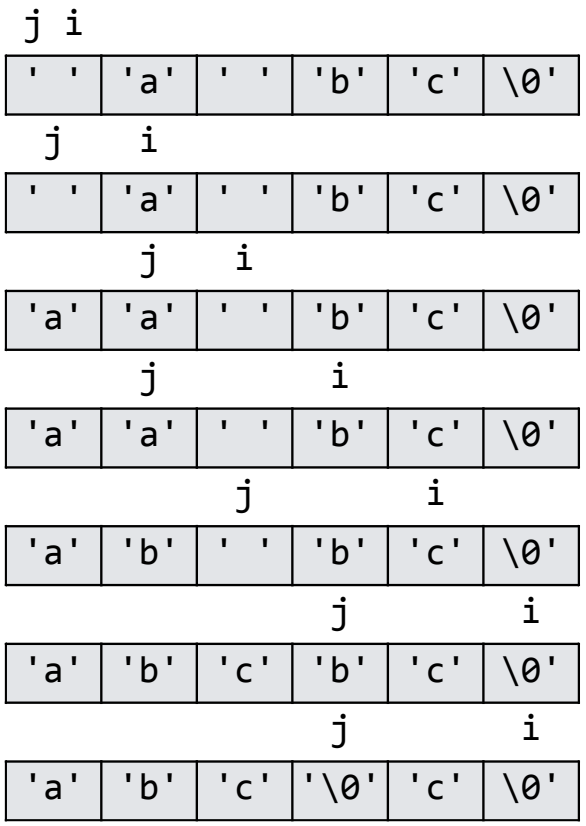
Remover espaços

```c
#include <ctype.h>

char *trim(char s[]) {
  int i, j = 0;
  char t[strlen(s)+1];
  for (i = 0; s[i] != '\0'; i++)
    if (!isspace(s[i])) {
      t[j] = s[i]; j++;
    }
  t[j] = '\0';
  for (i = 0; t[i] != '\0'; i++)
    s[i] = t[i];
  s[i] = '\0';
  return s;
}
```



Remover espaços

```c
#include <ctype.h>

char *trim(char s[]) {
  int i, j = 0;
  for (i = 0; s[i] != '\0'; i++)
    if (!isspace(s[i])) {
      s[j] = s[i]; j++;
    }
  s[j] = '\0';
  return s;
}
```



gets

```
char *gets(char s[]) {
  int i = 0;
  while ((s[i] = getchar()) != '\n') i++;
  s[i] = '\0';
  return s;
}
```

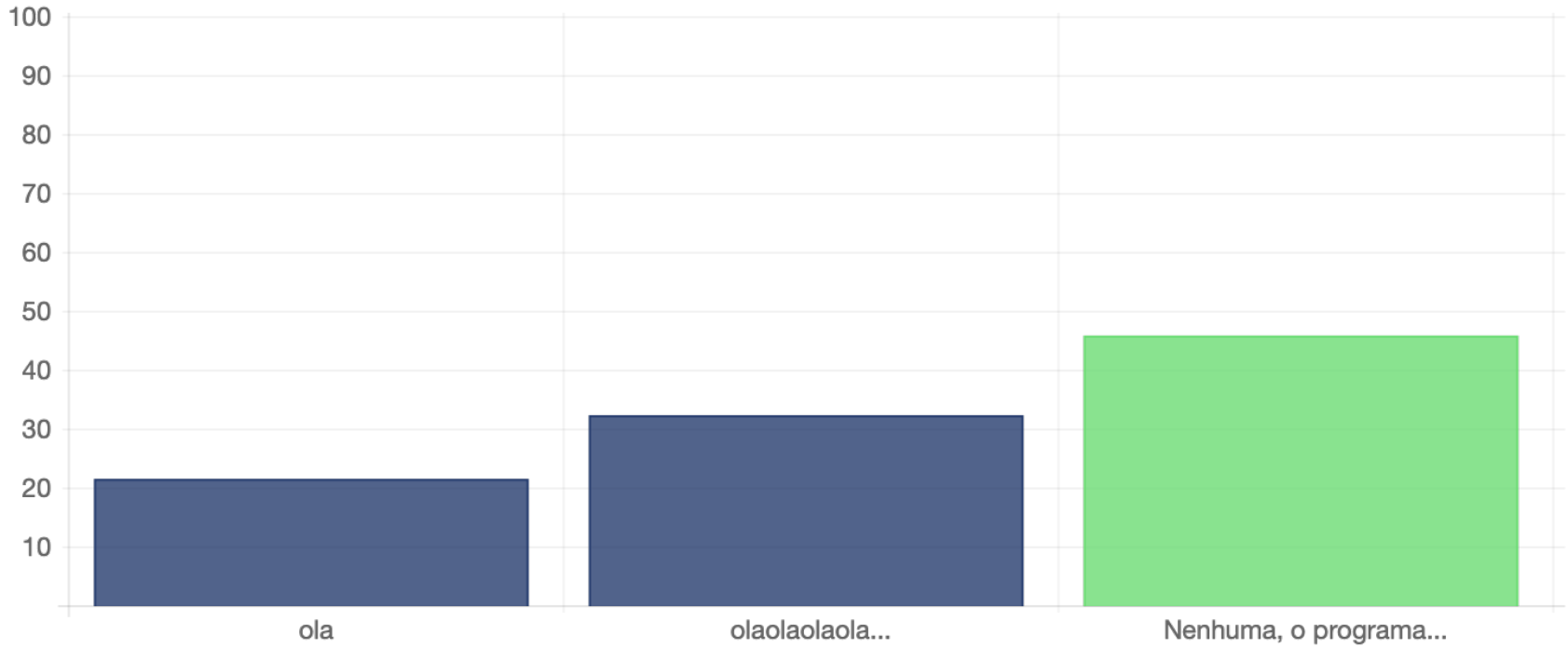
strcat

```
char *strcat(char s[], char t[]) {
  int i = strlen(s), j = 0;
  while (t[j] != '\0') {
    s[i] = t[j];
    i++; j++;
  }
  s[i] = '\0';
  return s;
}
```

#13 Que imprime o seguinte programa?

```
char *strcat(char s[], char t[]) {
  int i = strlen(s), j = 0;
  while (t[j] != '\0') {
    s[i] = t[j];
    i++; j++;
  }
  s[i] = '\0';
  return s;
}

int main() {
  char s[10] = "ola";
  printf("%s\n", strcat(s,s));
  return 0;
}
```

#13 Que imprime o seguinte programa?



Aula 9

Pesquisa linear num array

```
int search(int x, int a[], int n) {
  int i;
  for (i = 0; i < n && a[i] != x; i++);
  if (i < n) return 1;
  else return 0;
}
```

Sortear N inteiros diferentes

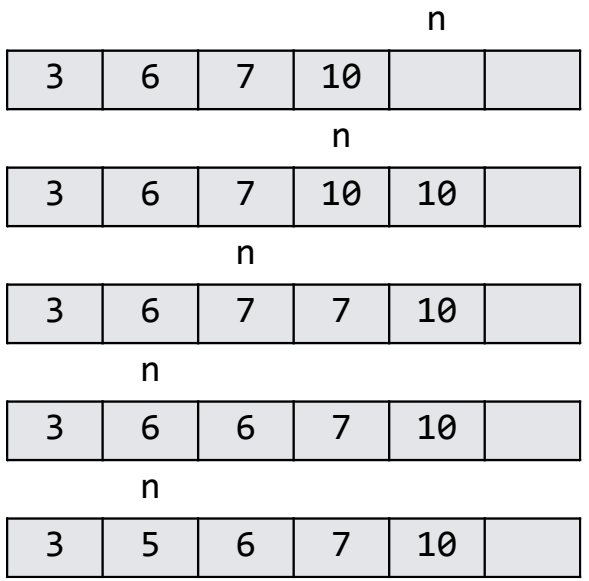
```
#define N 10

int main() {
  int i = 0, x, p[N];
  while (i < N) {
    x = rand();
    if (search(x,p,i)) continue;
    printf("%d\n", x);
    p[i] = x;
    i++;
  }
  return 0;
}
```

Pesquisa linear num array ordenado

```
int search(int x, int a[], int n) {
  int i;
  for (i = 0; i < n && a[i] < x; i++);
  if (i < n && a[i] == x) return 1;
  else return 0;
}
```

Inserção ordenada

```
void insert(int x, int a[], int n) {
  while (n > 0 && a[n-1] > x) {
    a[n] = a[n-1];
    n--;
  }
  a[n] = x;
}

int main() {
  int a[6] = {3,6,7,10};
  insert(5,a,4);
  return 0;
}
```

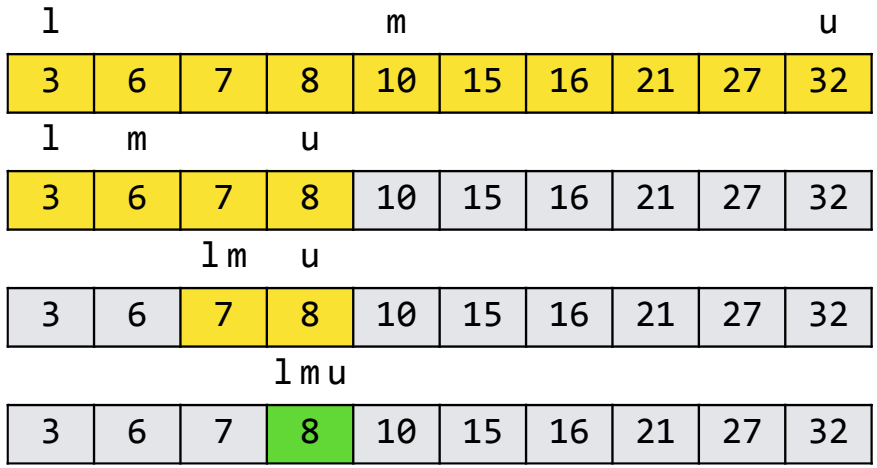


Sortear N inteiros diferentes

```
#define N 10

int main() {
  int i = 0, x, p[N];
  while (i < N) {
    x = rand();
    if (search(x,p,i)) continue;
    printf("%d\n", x);
    insert(x,p,i);
    i++;
  }
  return 0;
}
```

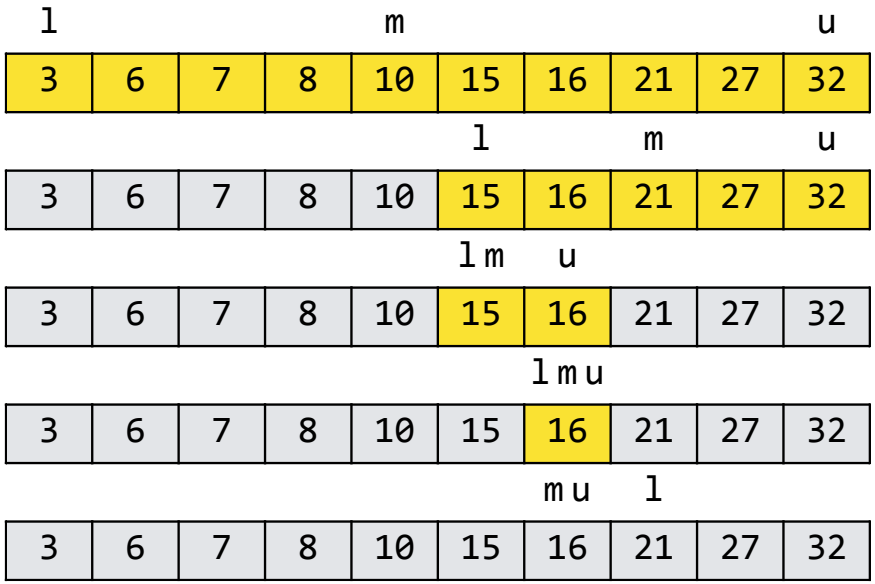
Pesquisa binária

```
int search(int x, int a[], int n) {
  int l = 0, u = n-1, m;
  while (l <= u) {
    m = (l+u) / 2;
    if (a[m] == x) return 1;
    if (a[m] < x) l = m+1;
    else u = m-1;
  }
  return 0;
}

int main() {
  int a[10] = {3,6,7,8,10,15,16,21,27,32};
  search(8,a,10);
  return 0;
}
```



Pesquisa binária

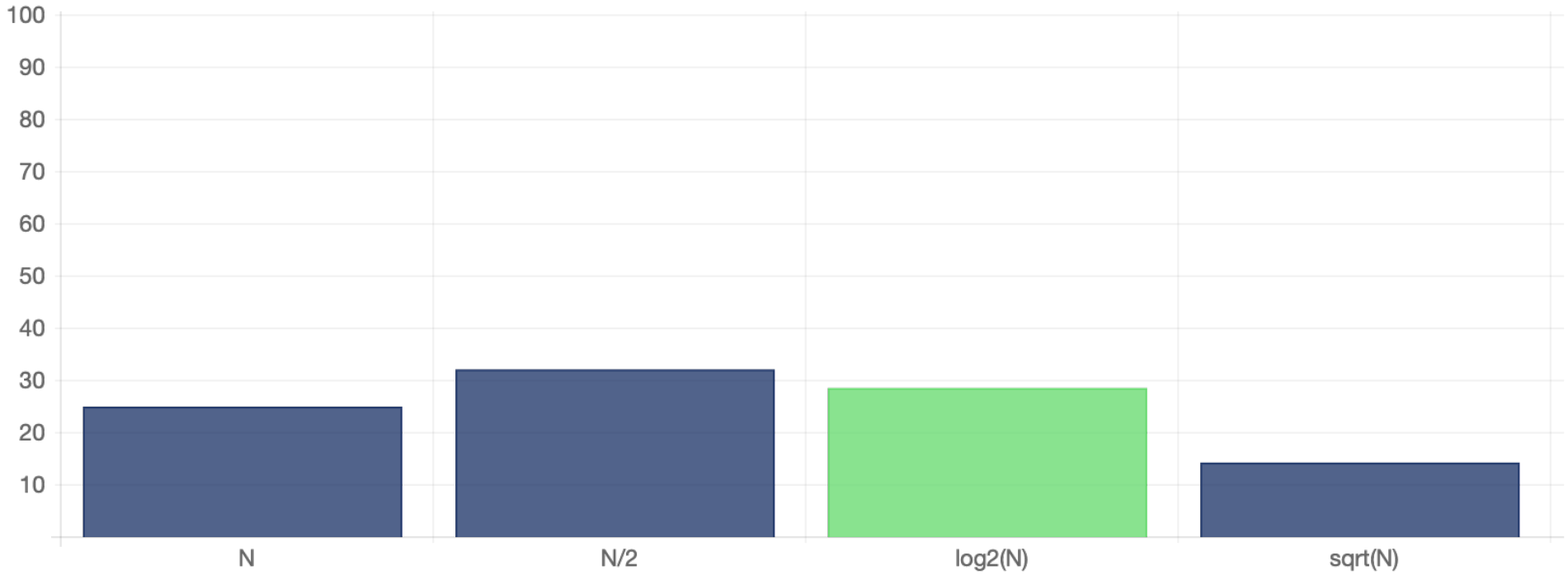
```
int search(int x, int a[], int n) {
  int l = 0, u = n-1, m;
  while (l <= u) {
    m = (l+u) / 2;
    if (a[m] == x) return 1;
    if (a[m] < x) l = m+1;
    else u = m-1;
  }
  return 0;
}

int main() {
  int a[10] = {3,6,7,8,10,15,16,21,27,32};
  search(20,a,10);
  return 0;
}
```



#14 Aproximadamente, quantas iterações fará o `search`?

```
#define N ...

int main() {
  int a[N];
  for (int i = 0; i < N; i++) a[i] = i;
  search(N,a,N);
}
```

#14 Aproximadamente, quantas iterações fará o `search`?



Pesquisa binária

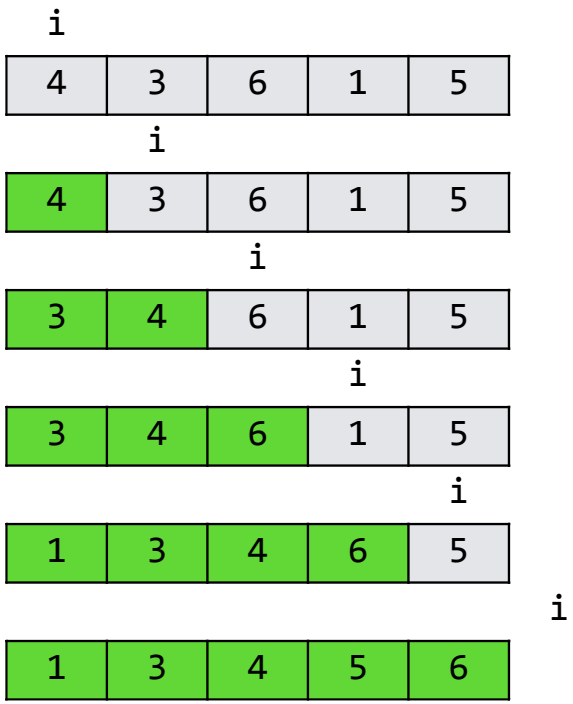
N	sqrt(N)	log2(N)
16	4	4
256	16	8
1024	32	10
1048576	1024	20

Insertion sort

```
void insert(int x, int a[], int n) {
  while (n > 0 && a[n-1] > x) {
    a[n] = a[n-1];
    n--;
  }
  a[n] = x;
}

void isort(int a[], int n) {
  if (n == 0) return;
  isort(a,n-1);
  insert(a[n-1],a,n-1);
}
```

Insertion sort

```
void insert(int x, int a[], int n) {
  while (n > 0 && a[n-1] > x) {
    a[n] = a[n-1];
    n--;
  }
  a[n] = x;
}

void isort(int a[], int n) {
  int i;
  for (i = 0; i < n; i++)
    insert(a[i],a,i);
}
```



Insertion sort

```
void isort(int a[], int n) {
  int i, j, aux;
  for (i = 0; i < n; i++) {
    aux = a[i];
    for (j = i; j > 0 && a[j-1] > aux; j--) a[j] = a[j-1];
    a[j] = aux;
  }
}
```

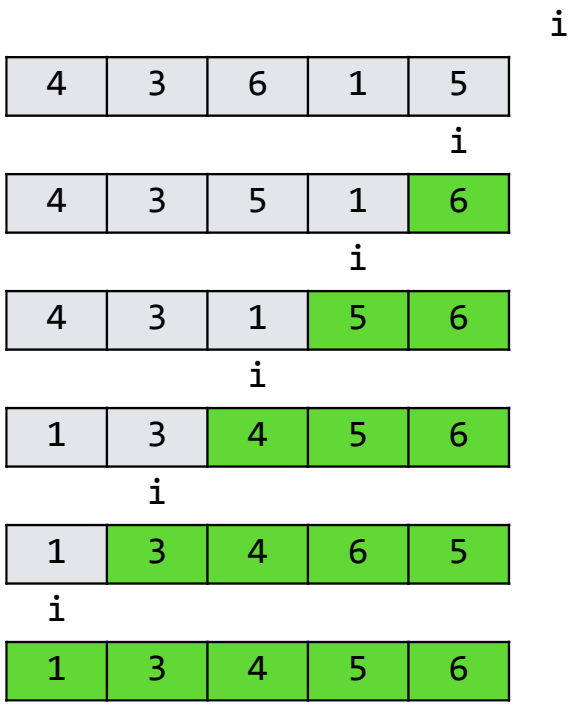
Aula 10

swap

```
void swap(int a[], int i, int j) {
  int aux = a[i];
  a[i] = a[j];
  a[j] = aux;
}
```

Selection sort

```
int max(int a[], int n) {
  int m = 0, i;
  for (i = 1; i < n; i++)
    if (a[i] > a[m]) m = i;
  return m;
}

void ssort(int a[], int n) {
  int i;
  for (i = n; i > 0; i--)
    swap(a, i-1, max(a,i));
}
```

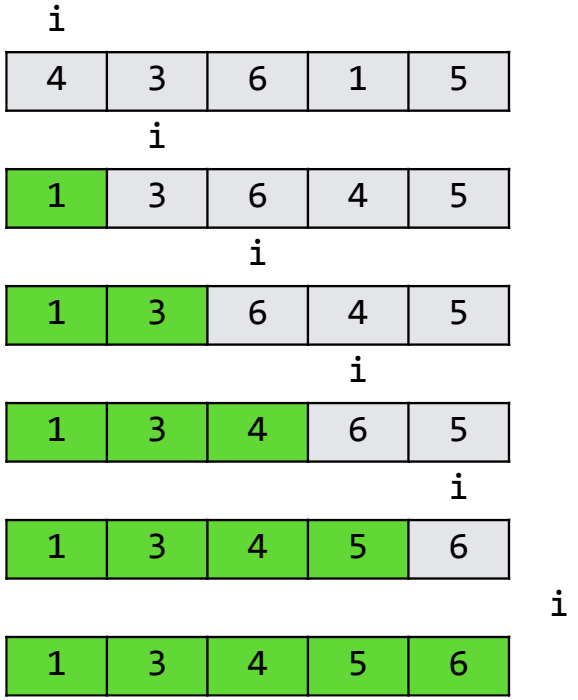


Selection sort

```
void ssort(int a[], int n) {
  int i, j, m;
  for (i = n; i > 0; i--) {
    m = 0;
    for (j = 0; j < i; j++)
      if (a[j] > a[m]) m = j;
    swap(a, i-1, m);
  }
}
```

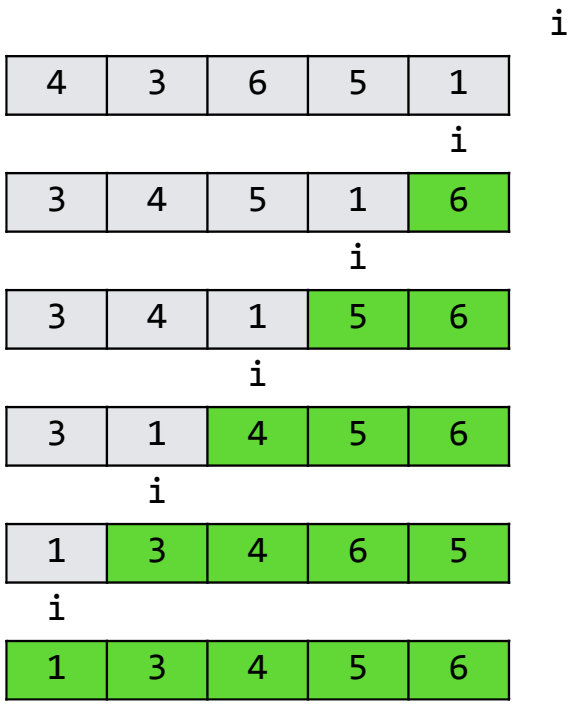
Selection sort

```
void ssort(int a[], int n) {
  int i, j, m;
  for (i = 0; i < n; i++) {
    m = i;
    for (j = i; j < n; j++)
      if (a[j] < a[m]) m = j;
    swap(a, i, m);
  }
}
```



Bubble sort

```
void bubble(int a[], int n) {
  int i;
  for (i = 1; i < n; i++)
    if (a[i-1] > a[i])
      swap(a, i-1, i);
}

void bsort(int a[], int n) {
  int i;
  for (i = n; i > 0; i--)
    bubble(a, i);
}
```

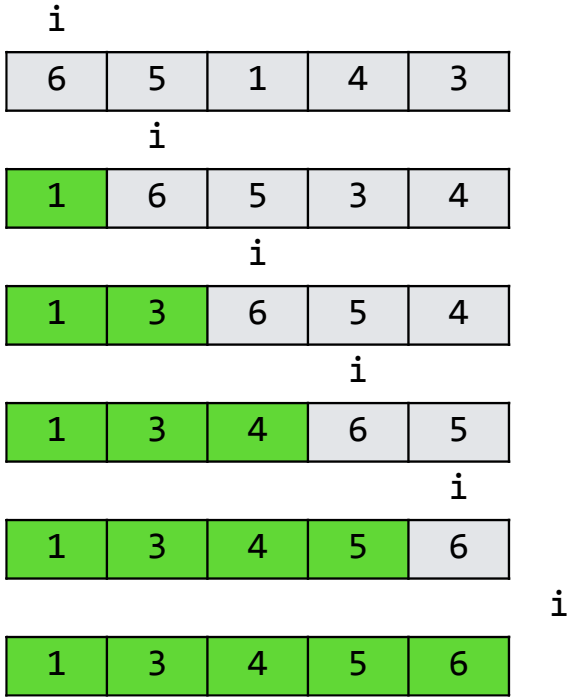


Bubble sort

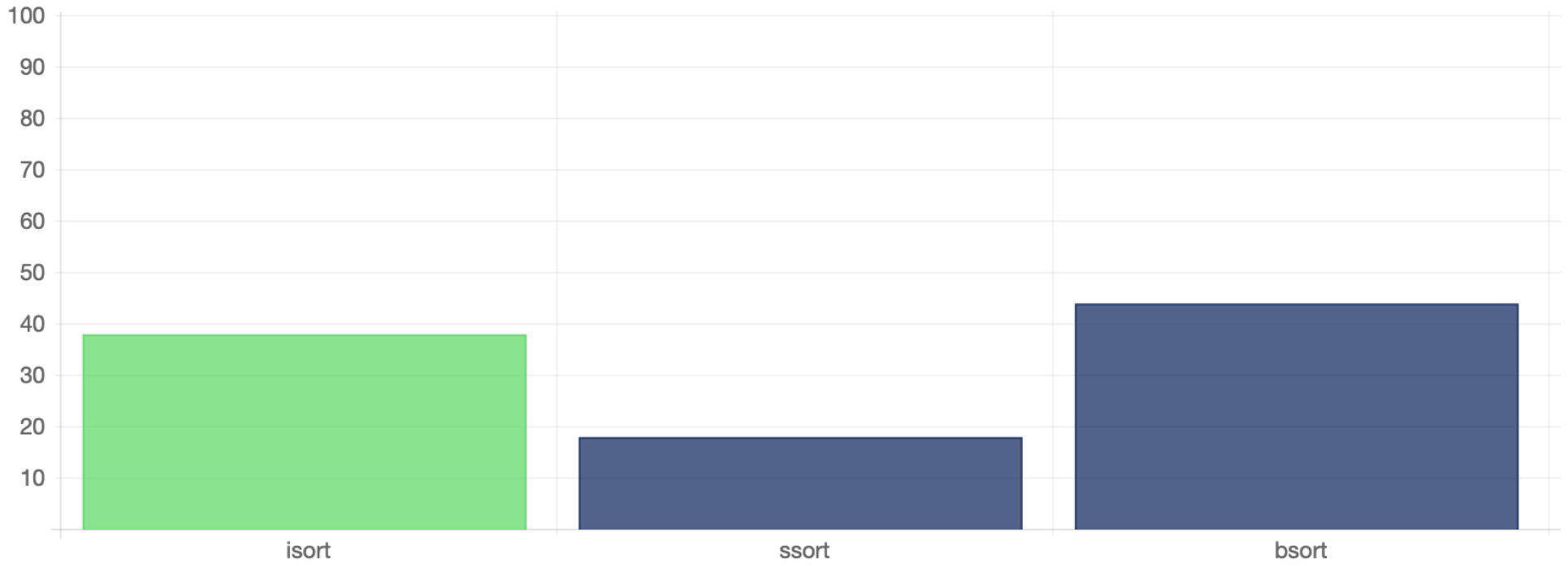
```
void bsort(int a[], int n) {
  int i, j;
  for (i = n; i > 0; i--)
    for (j = 1; j < i; j++)
      if (a[j-1] > a[j])
        swap(a, j-1, j);
}
```

Sinking sort

```
void bsort(int a[], int n) {
  int i, j;
  for (i = 0; i < n; i++)
    for (j = n-1; j > i; j--)
      if (a[j-1] > a[j])
        swap(a, j-1, j);
}
```



#15 Qual é mais rápido?

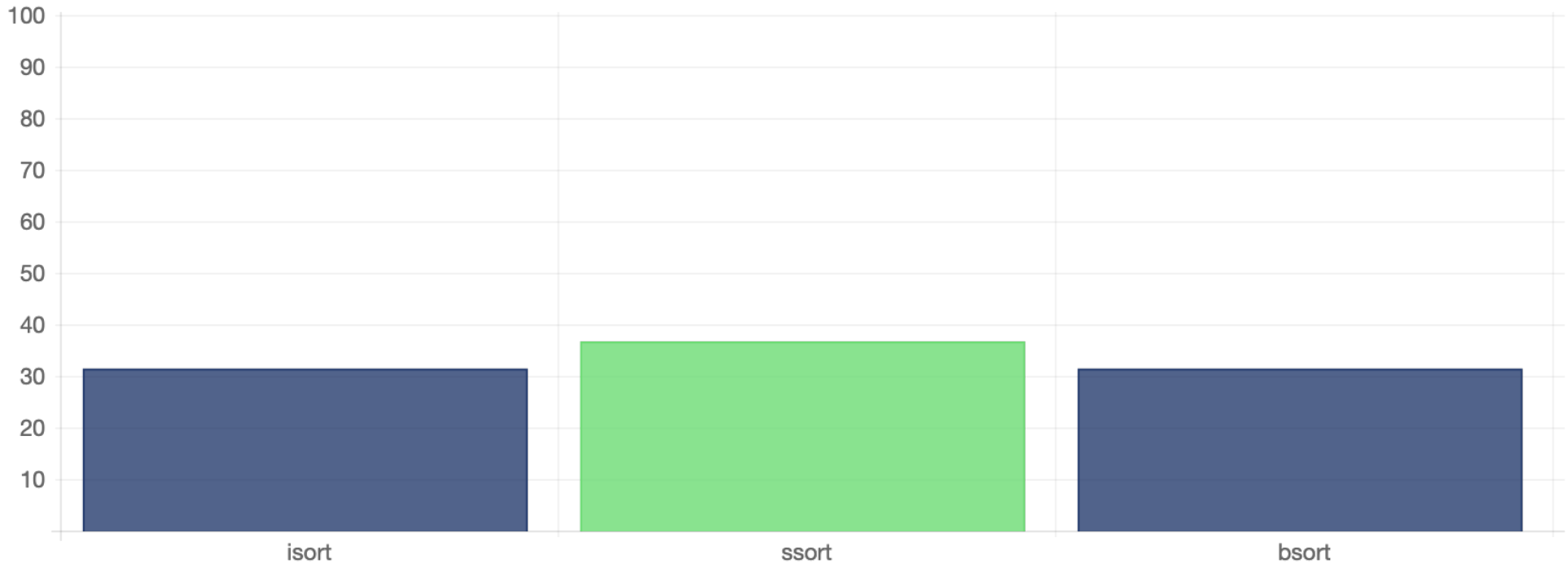


Aula 11

#16 Qual faz menos escritas no array?

```
int v[1000];
for (int i = 0; i < 1000; i++) v[i] = 999-i;
?sort(v,1000);
```

#16 Qual faz menos escritas no array?

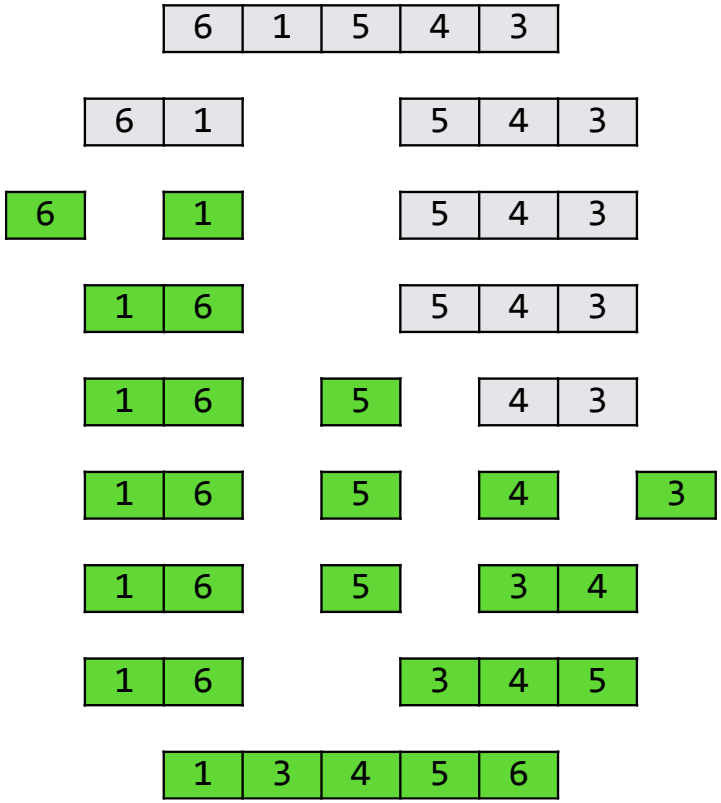


Merge sort

John von Neumann, 1945

Merge sort

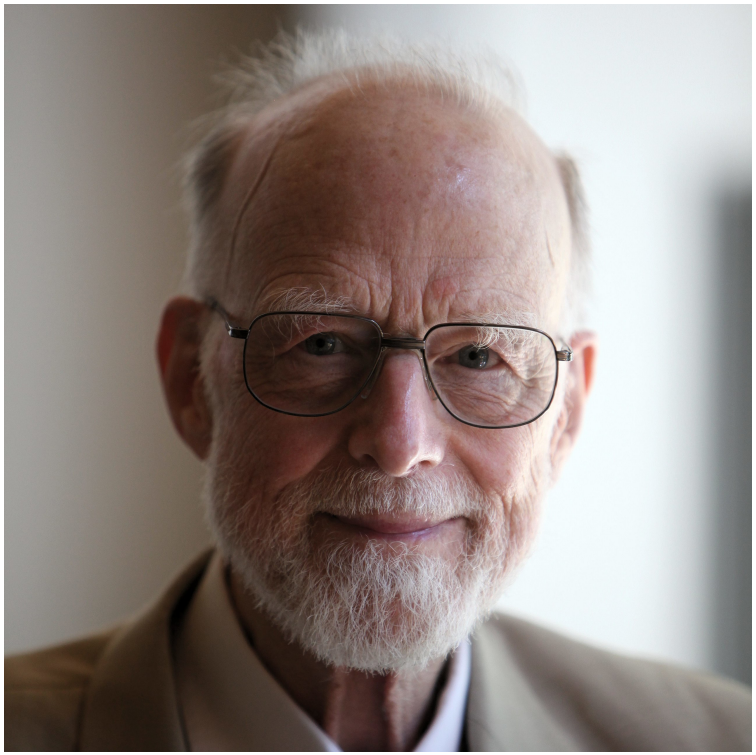
```
void msort(int a[], int n) {
  if (n < 2) return;
  int m = n/2;
  int aux[n];
  msort(a, m);
  msort(a+m, n-m);
  merge(a, m, a+m, n-m, aux);
  copy(aux, a, n);
}
```



Merge sort

```
void copy(int a[], int b[], int n) {
  for (int i = 0; i < n; i++) b[i] = a[i];
}

void merge(int a[], int na, int b[], int nb, int r[]) {
  ...
}
```

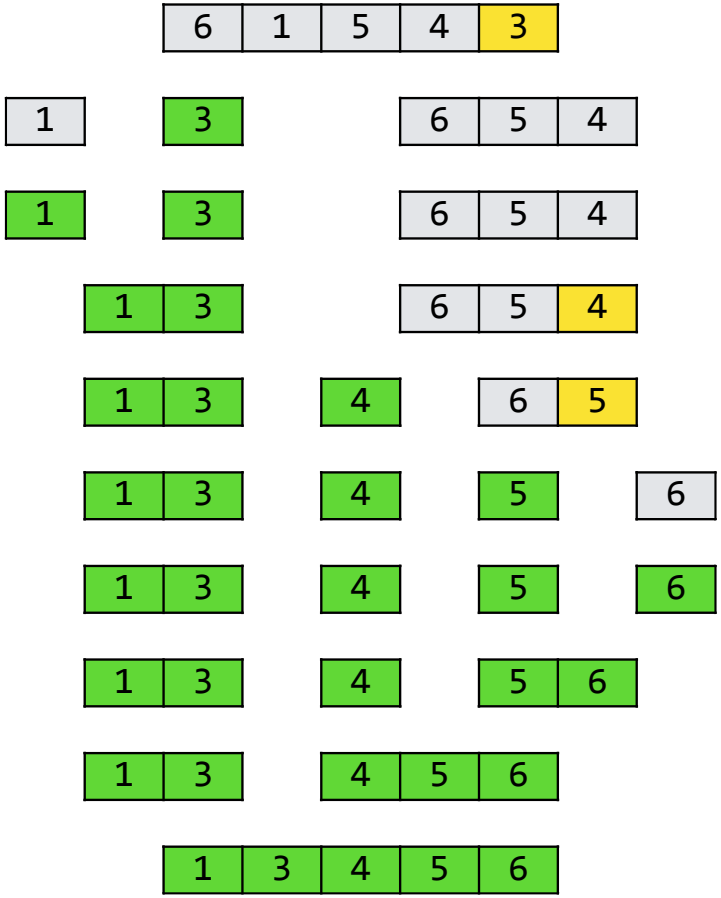
Quick sort



Tony Hoare, 1959

Quick sort

```
void qsort(int a[], int n) {
  if (n < 2) return;
  int p = partition(a, n-1, a[n-1]);
  swap(a, p, n-1);
  qsort(a, p);
  qsort(a+p+1, n-p-1);
}
```



Quick sort

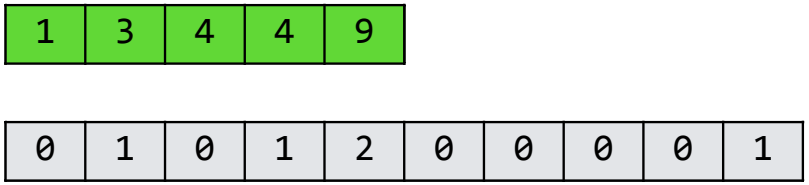
```
int partition(int a[], int n, int x) {
  ...
}
```

Eficiência

Algoritmo	Melhor	Pior
Insertion sort	N	N^2
Selection sort	N^2	N^2
Bubble sort	N	N^2
Merge sort	$N \cdot \log_2 N$	$N \cdot \log_2 N$
Quick sort	$N \cdot \log_2 N$	N^2

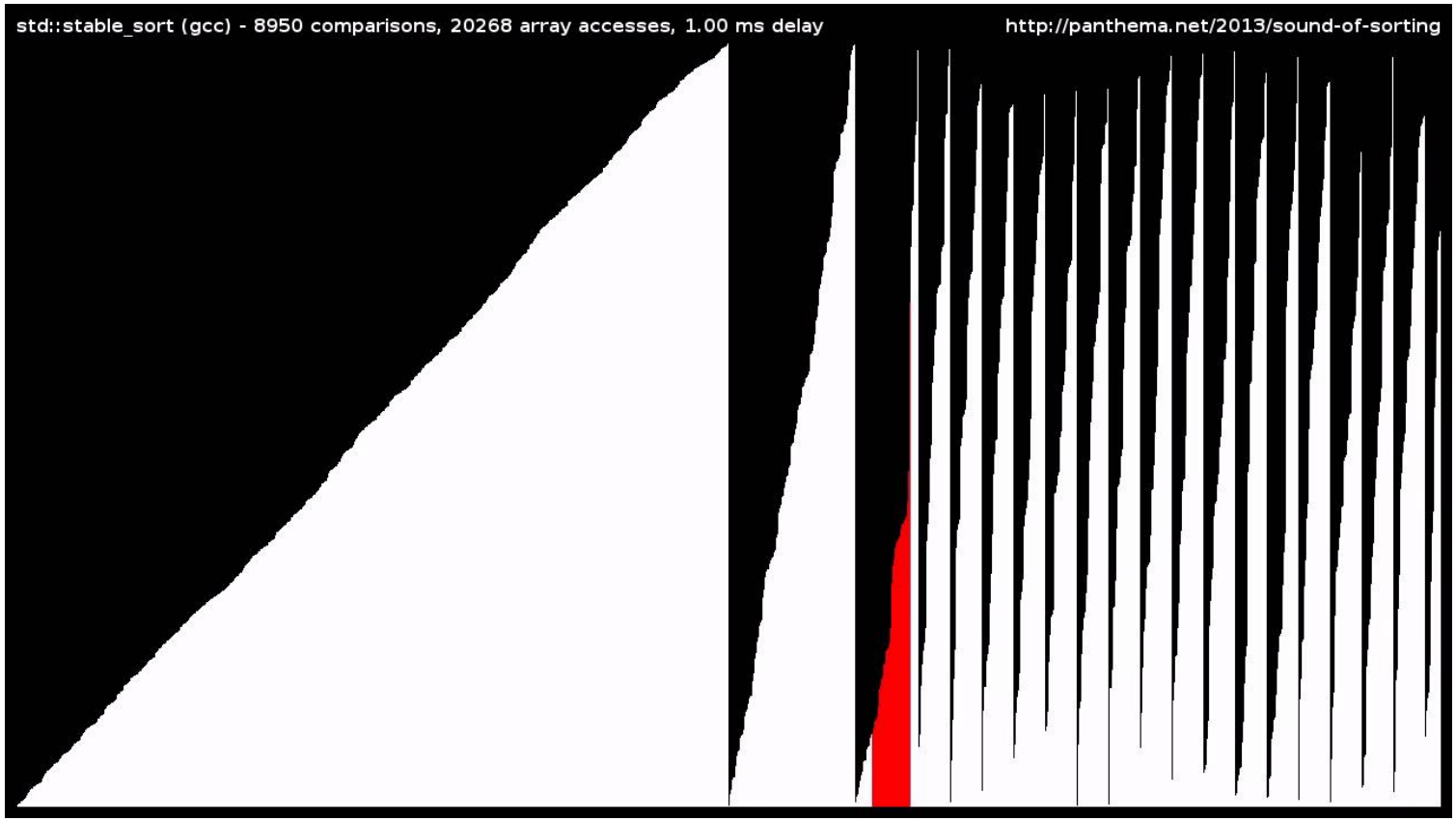
Counting sort

```
void csort(int a[], int n) {
  int c[10] = {0};
  int i, j, k;
  for (i = 0; i < n; i++) c[a[i]]++;
  i = 0;
  for (j = 0; j < 10; j++)
    for (k = 0; k < c[j]; k++)
      a[i++] = j;
}
```

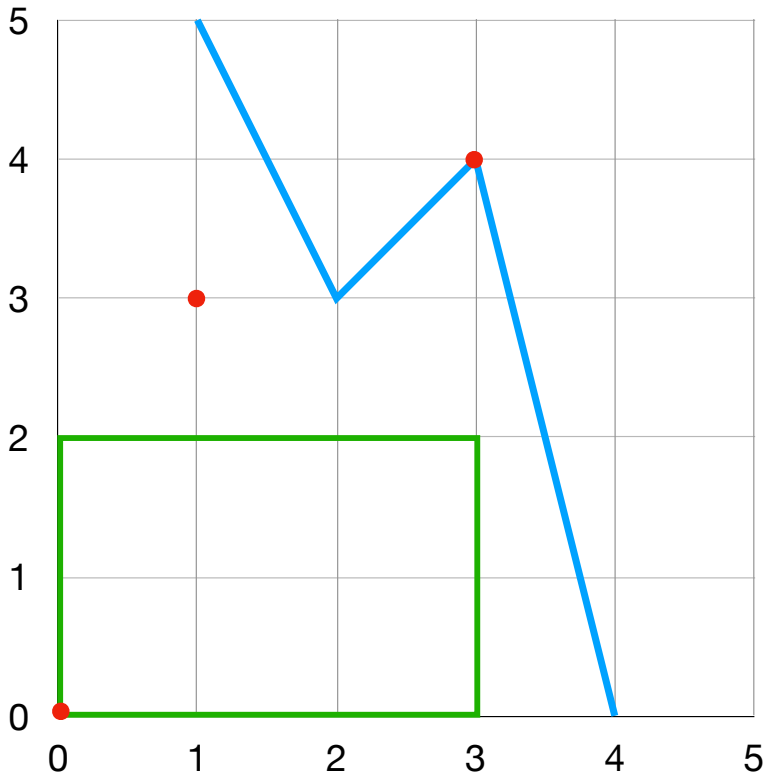


Let’s dance

The sound of sorting

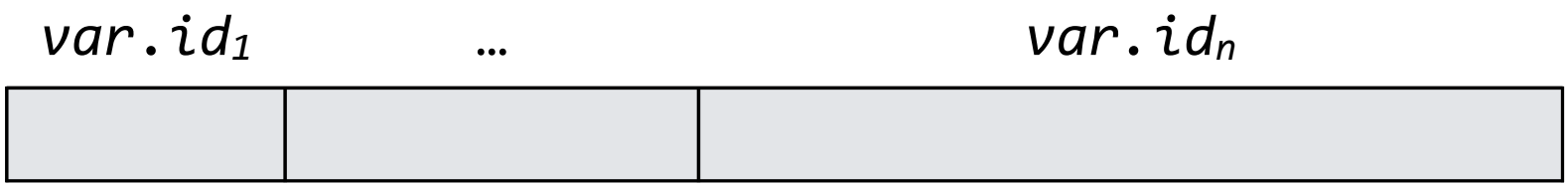


Pontos, rectângulos e poligonais



Declaração de structs

```
struct {
   tipo1 id1;
   …
   tipon idn;
} var;
```

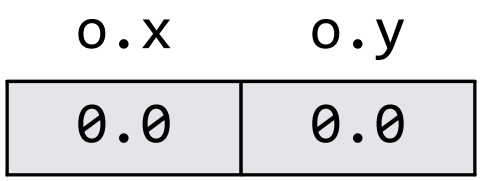


Inicialização de structs

```
struct {
   tipo1 id1;
   …
   tipon idn;
} var = {expr1, …, exprn};
```

Um ponto

```
struct {
   float x;
   float y;
} o = {0.0, 0.0};
```



Aula 12

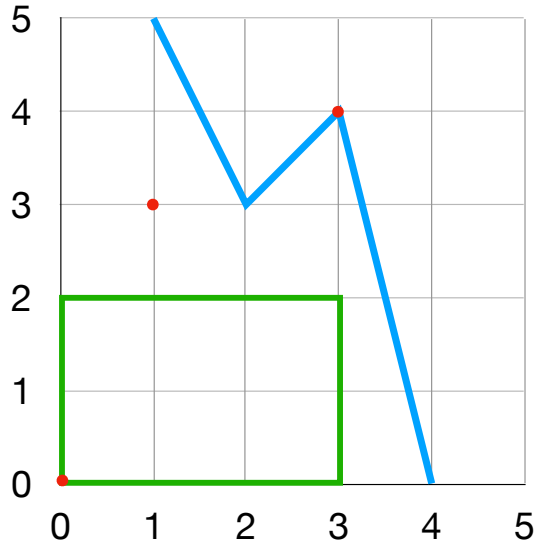
Declaração de um novo tipo `struct`

```
struct id {
  tipo1 id1;
  …
  tipon idn;
};

struct id var;
```

Pontos, rectângulos e poligonais

```
struct ponto {
  float x;
  float y;
};

struct rectangulo {
  struct ponto pt1, pt2;
};

#define MAX 100

struct poligonal {
  int tamanho;
  struct ponto pontos[MAX];
};
```

Pontos, rectângulos e poligonais



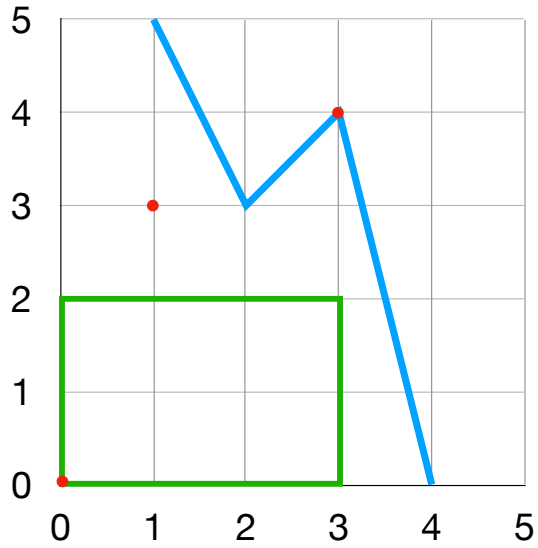

```
struct ponto o = {0,0};
struct ponto a = {1,3};
struct ponto b = {3,4};
struct rectangulo r = {o, {3,2}};
struct poligonal l = {4, {{1,5}, {2,3}, b, {4,0}}};
```

Operações com structs

- Pode-se aceder aos membros
- Podem-se copiar na totalidade
  - Em particular, são copiadas quando passadas a ou devolvidas por funções
- Não se podem comparar directamente
  - Tem que se comparar os membros

Pontos, rectângulos e poligonais

```
struct ponto o = {0,0};
struct ponto a = {1,3};
struct ponto b;
b.x = 3;
b.y = 4;
struct rectangulo r;
r.pt1 = o;
r.pt2.x = b.x;
r.pt2.y = 2;
struct poligonal l = {4, {{1,5}, {2,3}}};
l.pontos[2] = b;
l.pontos[3].x = 4;
l.pontos[3].y = 0;
```



Sinónimos de tipos

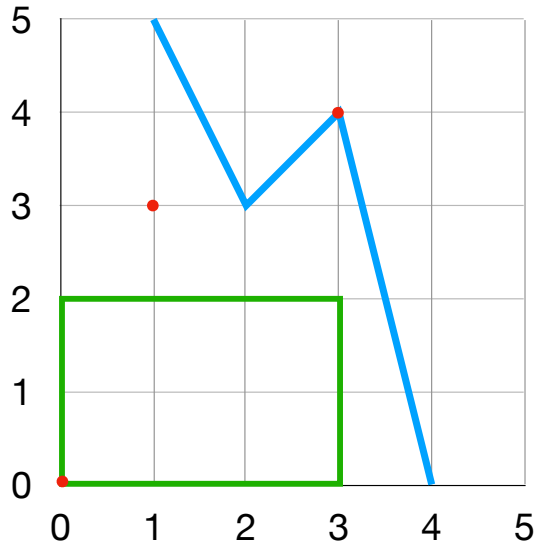
```
typedef tipo id;
```

Pontos, rectângulos e poligonais

```
struct pt {
  float x;
  float y;
};
typedef struct pt ponto;

typedef struct {
  ponto pt1, pt2;
} rectangulo;

#define MAX 100

struct poligonal {
  int tamanho;
  ponto pontos[MAX];
};
typedef struct poligonal poligonal;
```

Pontos, rectângulos e poligonais

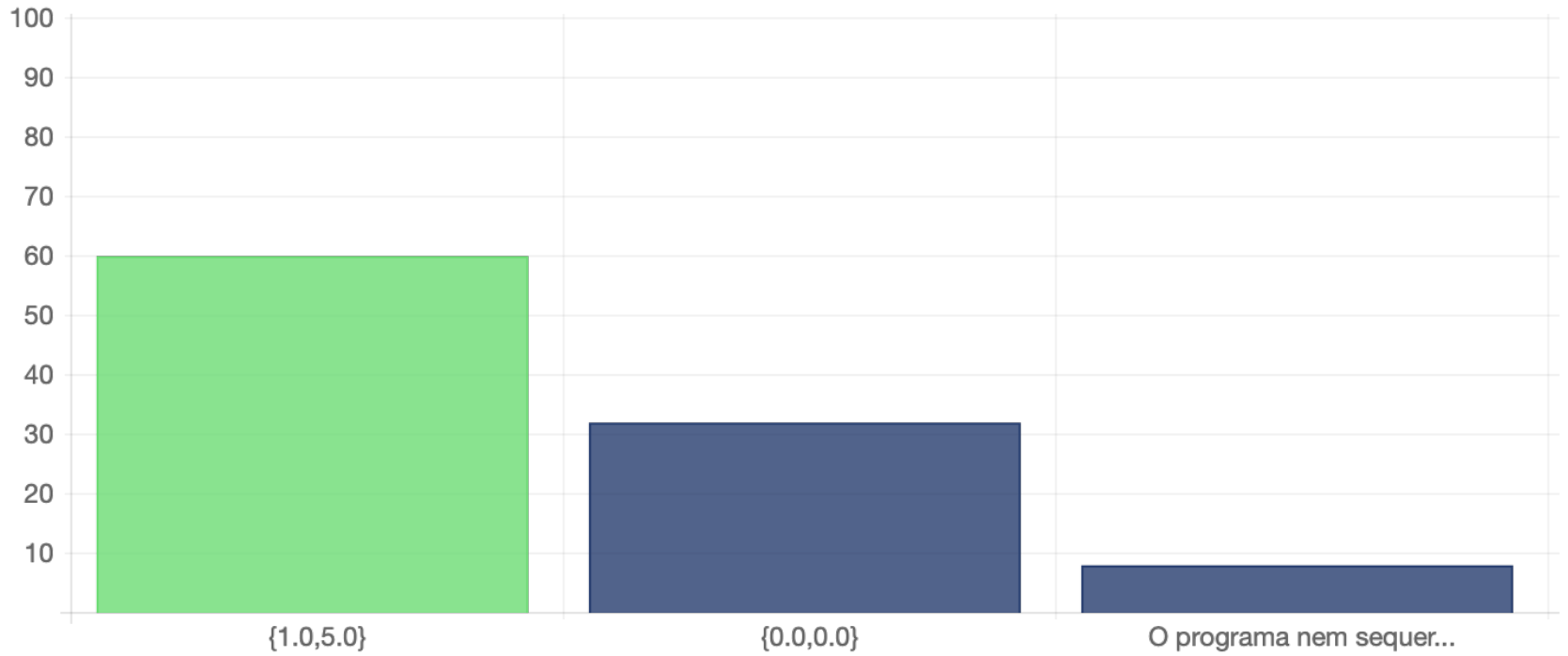
```
ponto o = {0,0};
ponto a = {1,3};
ponto b;
b.x = 3;
b.y = 4;
rectangulo r;
r.pt1 = o;
r.pt2.x = b.x;
r.pt2.y = 2;
poligonal l = {4, {{1,5}, {2,3}}};
l.pontos[2] = b;
l.pontos[3].x = 4;
l.pontos[3].y = 0;
```



#17 Qual o primeiro ponto de `m` no final?

```
ponto o = {0,0};
poligonal l = {4, {{1,5}, {2,3}, {3,4}, {4,0}}};
poligonal m = l;
l.pontos[0] = o;
printf("{%.1f,%.1f}\n", m.pontos[0].x, m.pontos[0].y);
```

#17 Qual o primeiro ponto de `m` no final?



Distância entre dois pontos

```
#include <math.h>

float dist(ponto a, ponto b) {
  return sqrt(pow(a.x - b.x, 2) + pow(a.y - b.y, 2));
}

int main() {
  ponto o = {0,0}, a = {1,3};
  printf("%.2f\n",dist(o,a));
  return 0;
}
```

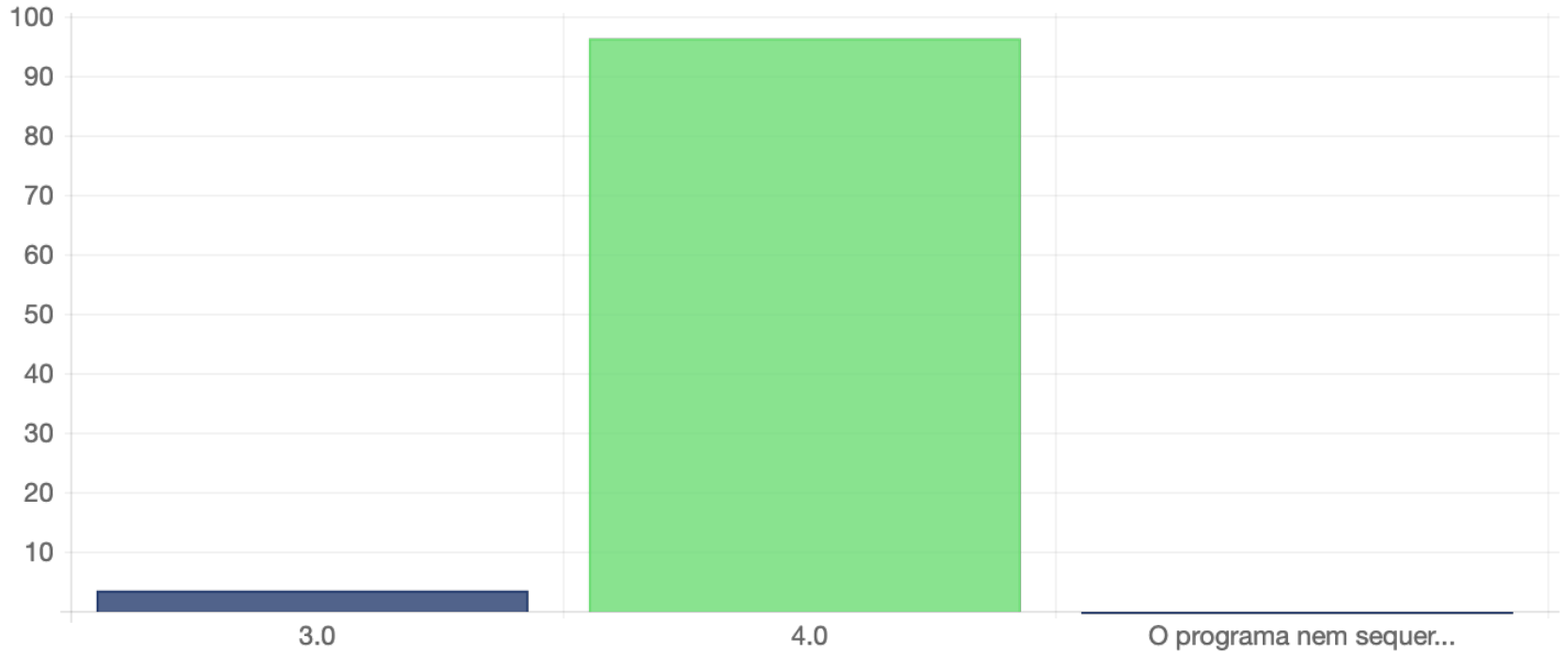
Área de um rectângulo

```
#include <math.h>

float area(rectangulo r) {
  return fabs(r.pt1.x - r.pt2.x) * fabs(r.pt1.y - r.pt2.y);
}

int main() {
  rectangulo r = {{0,0}, {3,2}};
  printf("%.2f\n",area(r));
  return 0;
}
```

#18 Qual a área de q?

```
rectangulo figura(ponto p, float d) {
  rectangulo r = {p, {p.x + d, p.y + d}};
  return r;
}

int main() {
  ponto a = {1,3};
  rectangulo q = figura(a, 2);
  printf("%.1f\n", area(q));
  return 0;
}
```

#18 Qual a área de q?

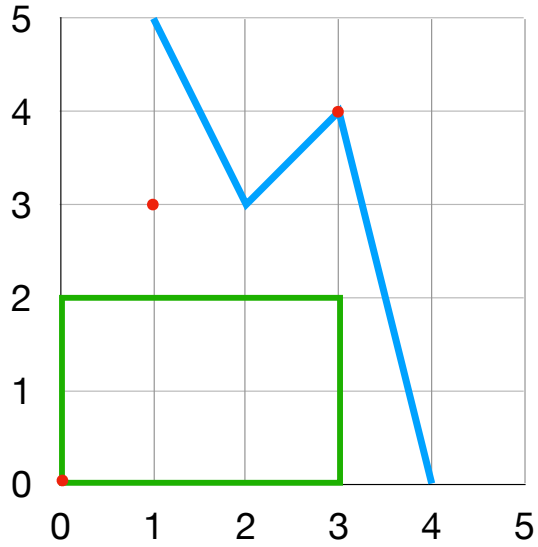


Poligonais coloridas

```
#define RED 0
#define GREEN 1
#define BLUE 2

#define MAX 100

struct poligonal {
  int tamanho;
  ponto pontos[MAX];
  int cor;
};
typedef struct poligonal poligonal;
```

Poligonais coloridas

```
ponto a = {1,5};
ponto b = {2,3};
ponto c = {3,4};
ponto d = {4,0};

poligonal l = {4, {a,b,c,d}, BLUE};
```



Declaração de um novo tipo `enum`

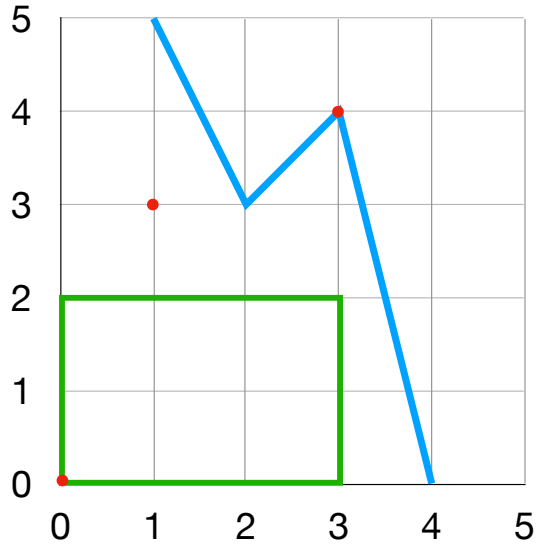
```
enum id {
   id1,
   …
   idn
};

enum id var;
```

Poligonais coloridas

```
enum cor {RED, GREEN, BLUE};
typedef enum cor cor;

#define MAX 100

struct poligonal {
  int tamanho;
  ponto pontos[MAX];
  cor cor;
};
typedef struct poligonal poligonal;
```

Poligonais coloridas

```
ponto a = {1,5};
ponto b = {2,3};
ponto c = {3,4};
ponto d = {4,0};

poligonal l = {4, {a,b,c,d}, BLUE};
```



Comprimento de uma poligonal

```
float comprimento(poligonal l) {
  float r = 0;
  for (int i = 1; i < l.tamanho; i++)
    r += dist(l.pontos[i-1], l.pontos[i]);
  return r;
}

int main() {
  poligonal l = {4, {{1,5}, {2,3}, {3,4}, {4,0}}, BLUE};
  printf("%.1f\n", comprimento(l));
  return 0;
}
```

Comprimento de uma poligonal

```
float comprimento(poligonal *l) {
  float r = 0;
  for (int i = 1; i < (*l).tamanho; i++)
    r += dist((*l).pontos[i-1], (*l).pontos[i]);
  return r;
}

int main() {
  poligonal l = {4, {{1,5}, {2,3}, {3,4}, {4,0}}, BLUE};
  printf("%.1f\n", comprimento(&l));
  return 0;
}
```

Acesso a membro via apontador

```
(*var).id
==
var->id
```

Comprimento de uma poligonal

```
float comprimento(poligonal *l) {
  float r = 0;
  for (int i = 1; i < l->tamanho; i++)
    r += dist(l->pontos[i-1], l->pontos[i]);
  return r;
}

int main() {
  poligonal l = {4, {{1,5}, {2,3}, {3,4}, {4,0}}, BLUE};
  printf("%.1f\n", comprimento(&l));
  return 0;
}
```

Estender uma poligonal

```
int estende(poligonal *l, ponto p) {
  if (l->tamanho == MAX) return 1;
  l->pontos[l->tamanho] = p;
  l->tamanho++;
  return 0;
}

int main() {
  ponto o = {0,0};
  poligonal l = {4, {{1,5}, {2,3}, {3,4}, {4,0}}, BLUE};
  estende(&l, o);
  printf("%.1f\n", comprimento(&l));
  return 0;
}
```

Aula 13

Arrays dinâmicos

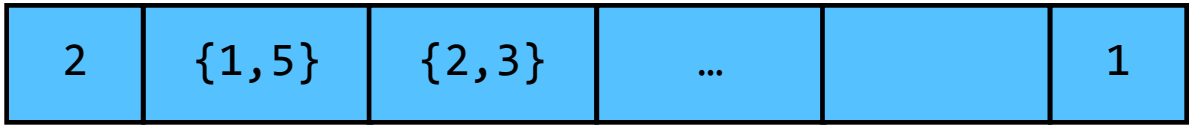
- Arrays que crescem ou diminuem conforme a necessidade de espaço
- Suportados nativamente em muitas linguagens modernas
  - Java (`ArrayList`), C++ (`std::vector`), Python (`list`), …
- Tipicamente, quando ficam cheios duplicam a capacidade
  - Operação pouco eficiente, mas executada poucas vezes
- C não tem suporte nativo para arrays dinâmicos
  - Mas podem ser implementados com operações explícitas de gestão de memória

`malloc` e `free`

- A função `malloc` aloca (reserva) um dado número de bytes na *heap*
  - Devolve um apontador para o primeiro byte alocado
  - Os bytes alocados são contíguos
  - Devolve o apontador `NULL` se não foi possível alocar
  - Deve ser usada a primitiva `sizeof` para calcular o número de bytes a alocar
- A função `free` liberta espaço previamente alocado
- Declaradas na biblioteca `<stdlib.h>`

Poligonal com array na *stack*

```
#define MAX 100

typedef struct {
  int tamanho;
  ponto pontos[MAX];
  cor cor;
} poligonal;

int main() {
  ponto a = {1,5}, b = {2,3};
  poligonal l;
  l.tamanho = 0;
  l.cor = GREEN;
  extende(&l,a);
  extende(&l,b);
  return 0;
}
```

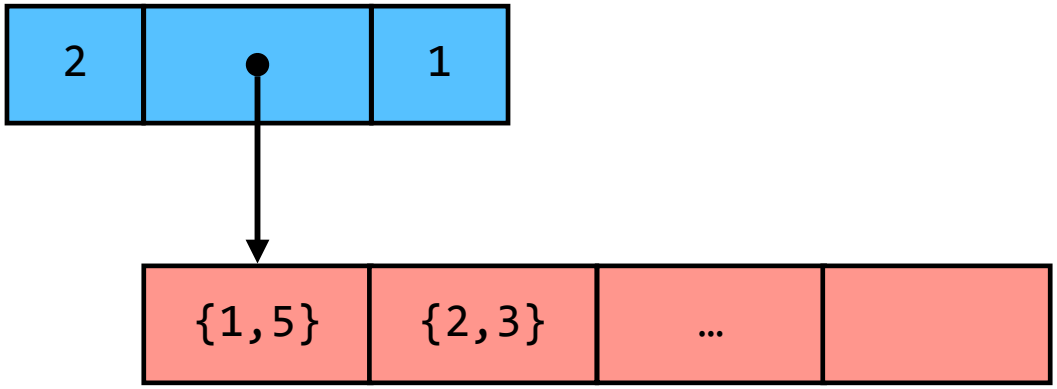


Poligonal com array na *heap*

```c
#define MAX 100

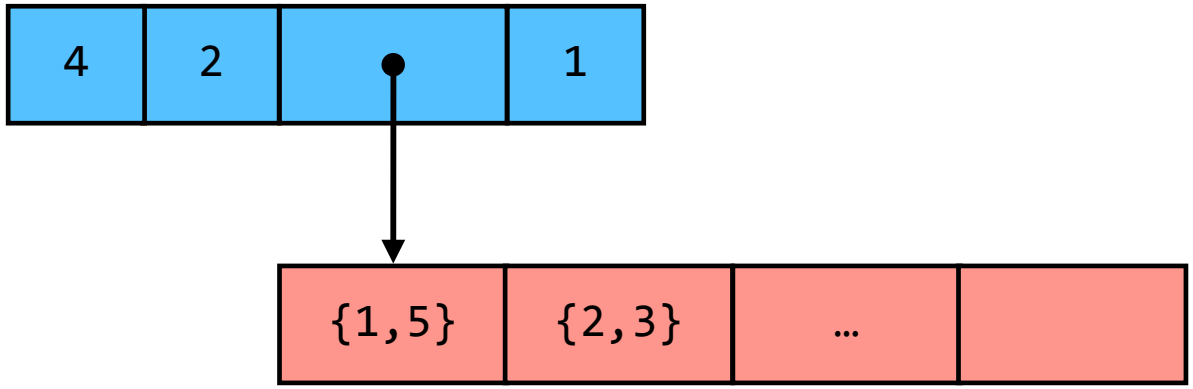
typedef struct {
  int tamanho;
  ponto *pontos;
  cor cor;
} poligonal;

int main() {
  ponto a = {1,5}, b = {2,3};
  poligonal l;
  l.tamanho = 0;
  l.cor = GREEN;
  l.pontos = malloc(sizeof(ponto) * MAX);
  extende(&l,a);
  extende(&l,b);
  free(l.pontos);
  return 0;
}
```



Poligonal com array dinâmico

```
typedef struct {
  int capacidade;
  int tamanho;
  ponto *pontos;
  cor cor;
} poligonal;
```



aloca e liberta

```
#define MIN 1

int aloca(poligonal *l, cor c) {
  l->capacidade = MIN;
  l->tamanho = 0;
  l->cor = c;
  l->pontos = malloc(l->capacidade * sizeof(ponto));
  if (l->pontos == NULL) return 1;
  else return 0;
}

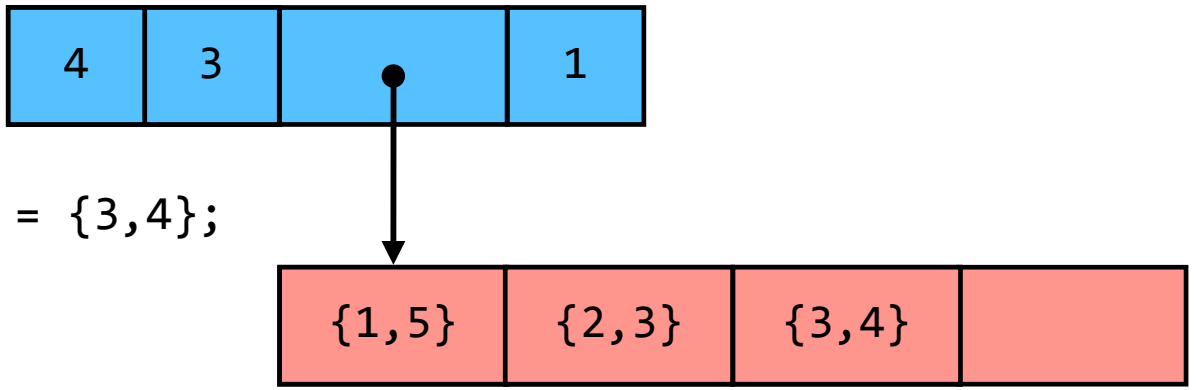
void liberta(poligonal *l) {
  free(l->pontos);
}
```

estende

```
int estende(poligonal *l, ponto p) {
  if (l->tamanho == l->capacidade) {
    ponto *new = malloc(2 * l->capacidade * sizeof(ponto));
    if (new == NULL) return 1;
    for (int i = 0; i < l->tamanho; i++) new[i] = l->pontos[i];
    free(l->pontos);
    l->pontos = new;
    l->capacidade *= 2;
  }
  l->pontos[l->tamanho] = p;
  l->tamanho++;
  return 0;
}
```

Poligonal com array dinâmico

```
int main() {
  ponto a = {1,5}, b = {2,3}, c = {3,4};
  poligonal l;
  aloca(&l,GREEN);
  estende(&l,a);
  estende(&l,b);
  estende(&l,c);
  liberta(&l);
  return 0;
}
```



`realloc`

- A função `realloc` permite alterar o tamanho do espaço alocado
  - Recebe um apontador para o espaço actual e o novo tamanho desejado
  - Tenta primeiro alocar o espaço adicional depois do espaço actual
  - Se não for possível aloca numa nova zona da *heap*, transfere o conteúdo e liberta o espaço anterior
  - Se também não for possível devolve `NULL`
  - Neste caso não liberta o espaço anterior

estende

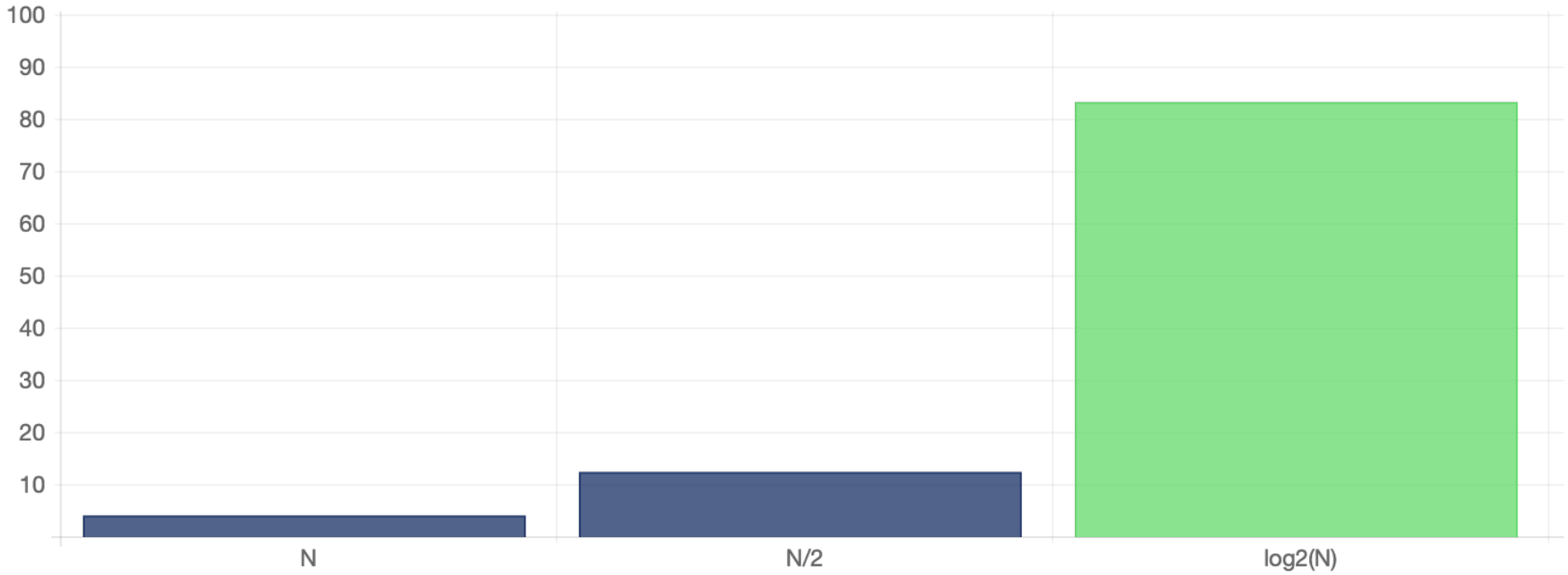
```
int estende(poligonal *l, ponto p) {
  if (l->tamanho == l->capacidade) {
    ponto *new = realloc(l->pontos, 2 * l->capacidade * sizeof(ponto));
    if (new == NULL) return 1;
    l->pontos = new;
    l->capacidade *= 2;
  }
  l->pontos[l->tamanho] = p;
  l->tamanho++;
  return 0;
}
```

#19 Aproximadamente, quantos `reallocs` serão feitos?

```
#define N …

int main() {
  ponto p;
  poligonal l;
  aloca(&l,GREEN);
  for (int i = 0; i < N; i++) {
    p.x = i; p.y = i;
    estende(&l, p);
  }
  liberta(&l);
  return 0;
}
```

#19 Aproximadamente, quantos `reallocs` serão feitos?

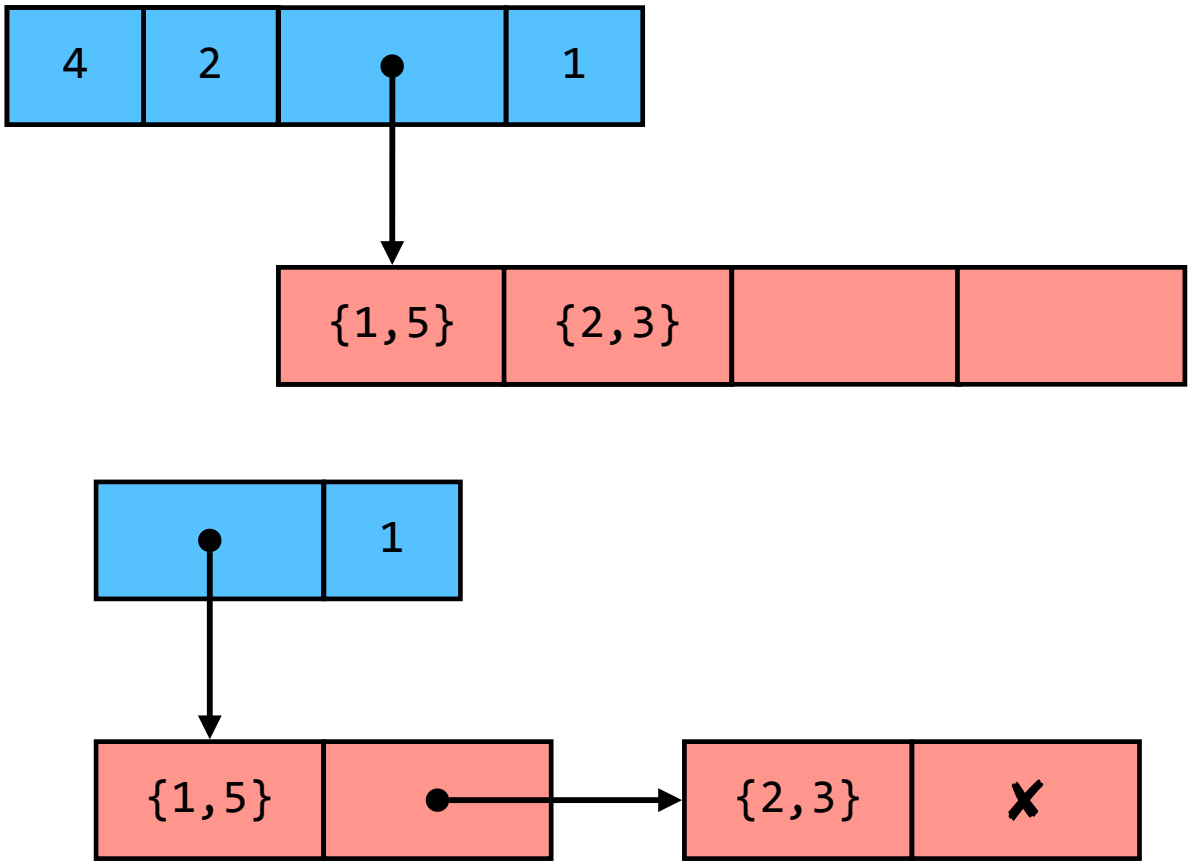


Arrays dinâmicos

- Permitem implementar arrays de tamanho variável
- Com operações de leitura e escrita muito eficientes, tal como nos arrays normais
- Mas com uma operação ocasional de redimensionamento pouco eficiente
- E também podem ter muito espaço desperdiçado
- Existem outras estruturas de dados dinâmicas com operações cuja eficiência pode ser mais previsível
- E com espaço ocupado proporcional ao tamanho do conteúdo

Aula 14

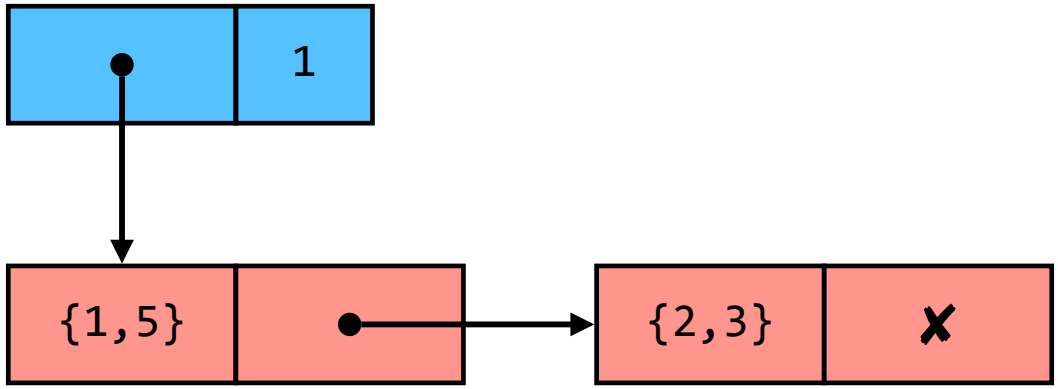
Arrays dinâmicos vs Listas ligadas



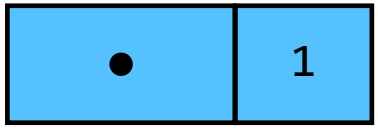
Poligonal com lista ligada

```
typedef struct lponto_no {
  ponto ponto;
  struct lponto_no *prox;
} *lponto;

typedef struct {
  lponto pontos;
  cor cor;
} poligonal;
```



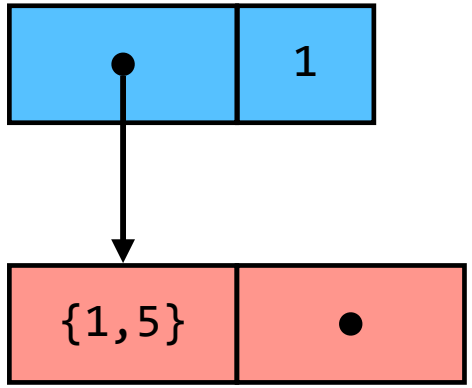
Poligonal com lista ligada




```
int main() {
  ponto a = {1,5}, b = {2,3};
  poligonal l;
  l.cor = GREEN;
  l.pontos = malloc(sizeof(struct lponto_no));
  l.pontos->ponto = a;
  l.pontos->prox = malloc(sizeof(struct lponto_no));
  l.pontos->prox->ponto = b;
  l.pontos->prox->prox = NULL;
  free(l.pontos->prox);
  free(l.pontos);
  return 0;
}
```

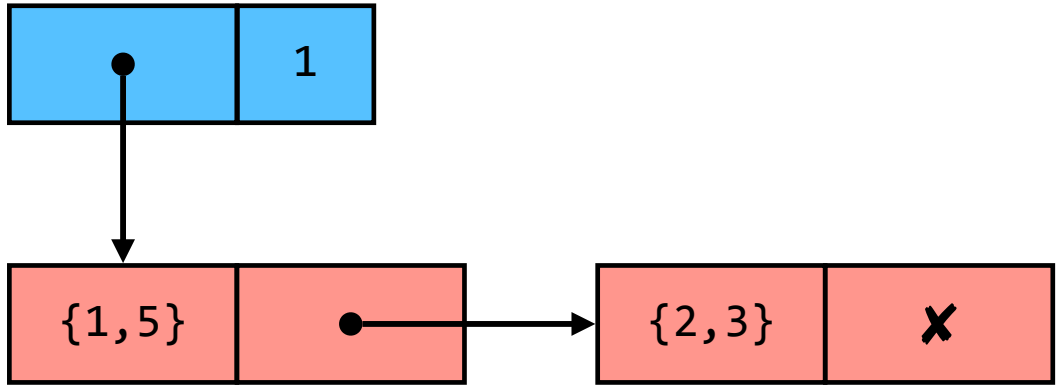
Poligonal com lista ligada

```
int main() {
  ponto a = {1,5}, b = {2,3};
  poligonal l;
  l.cor = GREEN;
  l.pontos = malloc(sizeof(struct lponto_no));
  l.pontos->ponto = a;
  l.pontos->prox = malloc(sizeof(struct lponto_no));
  l.pontos->prox->ponto = b;
  l.pontos->prox->prox = NULL;
  free(l.pontos->prox);
  free(l.pontos);
  return 0;
}
```

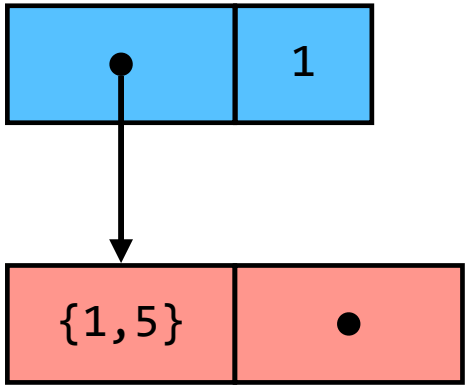


Poligonal com lista ligada

```
int main() {
  ponto a = {1,5}, b = {2,3};
  poligonal l;
  l.cor = GREEN;
  l.pontos = malloc(sizeof(struct lponto_no));
  l.pontos->ponto = a;
  l.pontos->prox = malloc(sizeof(struct lponto_no));
  l.pontos->prox->ponto = b;
  l.pontos->prox->prox = NULL;
  free(l.pontos->prox);
  free(l.pontos);
  return 0;
}
```

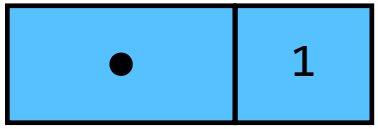


Poligonal com lista ligada



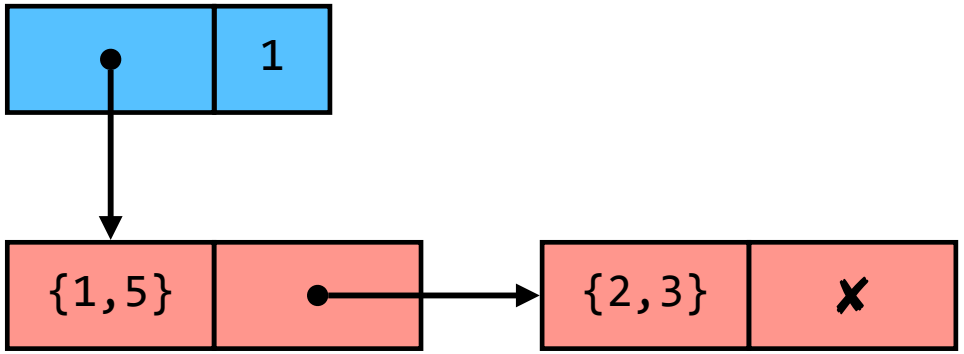

```
int main() {
  ponto a = {1,5}, b = {2,3};
  poligonal l;
  l.cor = GREEN;
  l.pontos = malloc(sizeof(struct lponto_no));
  l.pontos->ponto = a;
  l.pontos->prox = malloc(sizeof(struct lponto_no));
  l.pontos->prox->ponto = b;
  l.pontos->prox->prox = NULL;
  free(l.pontos->prox);
  free(l.pontos);
  return 0;
}
```

Poligonal com lista ligada



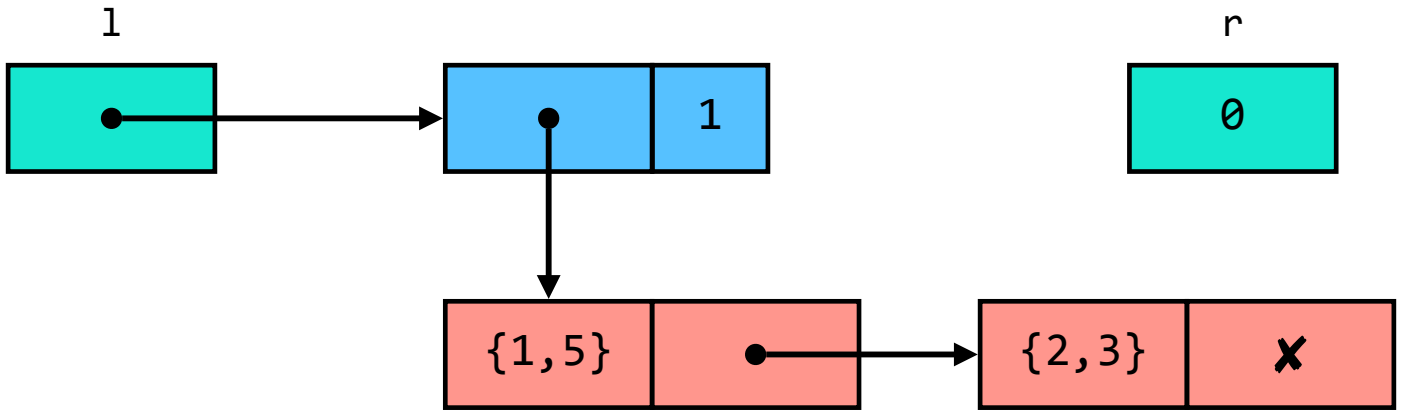

```
int main() {
  ponto a = {1,5}, b = {2,3};
  poligonal l;
  l.cor = GREEN;
  l.pontos = malloc(sizeof(struct lponto_no));
  l.pontos->ponto = a;
  l.pontos->prox = malloc(sizeof(struct lponto_no));
  l.pontos->prox->ponto = b;
  l.pontos->prox->prox = NULL;
  free(l.pontos->prox);
  free(l.pontos);
  return 0;
}
```

tamanho



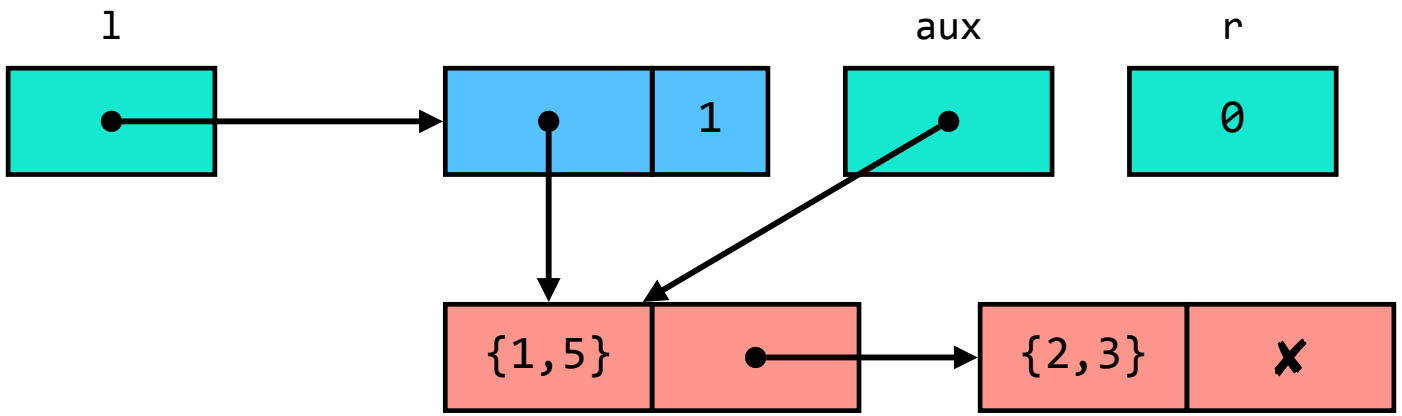

```
int tamanho(poligonal *l) {
  int r = 0;
  for (lponto aux = l->pontos; aux != NULL; aux = aux->prox) r++;
  return r;
}
```

tamanho



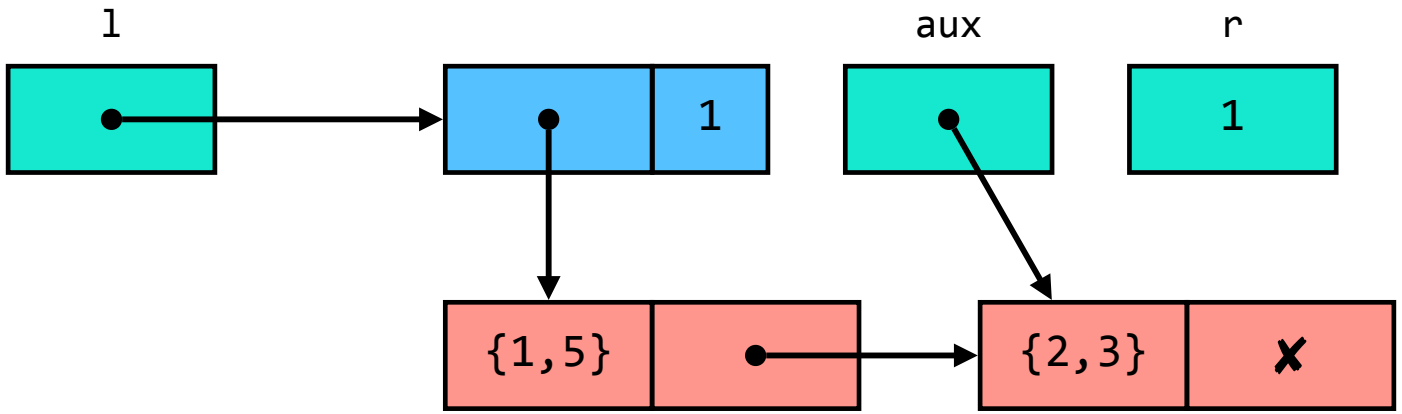

```
int tamanho(poligonal *l) {
  int r = 0;
  for (lponto aux = l->pontos; aux != NULL; aux = aux->prox) r++;
  return r;
}
```

tamanho



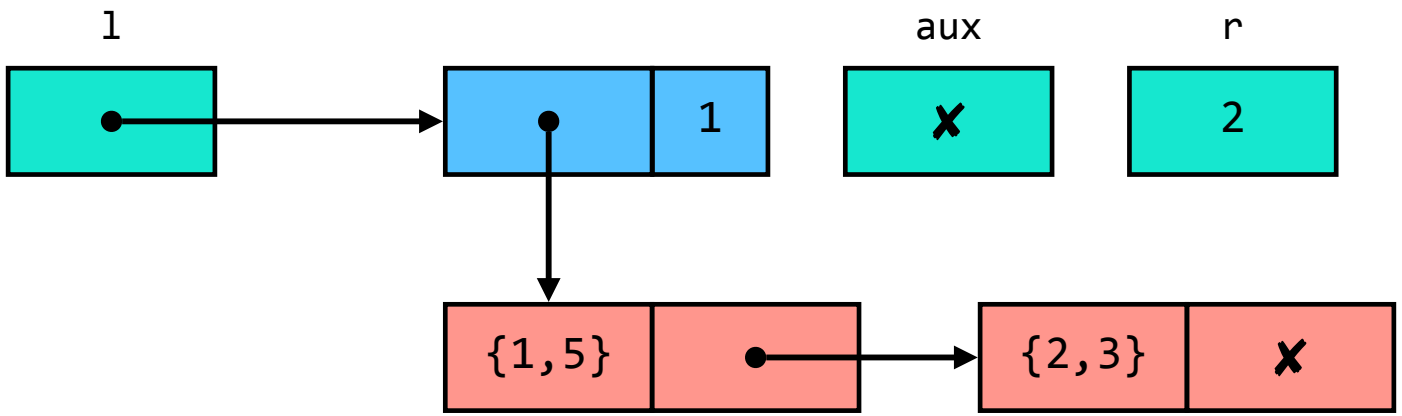

```
int tamanho(poligonal *l) {
  int r = 0;
  for (lponto aux = l->pontos; aux != NULL; aux = aux->prox) r++;
  return r;
}
```

tamanho




```
int tamanho(poligonal *l) {
  int r = 0;
  for (lponto aux = l->pontos; aux != NULL; aux = aux->prox) r++;
  return r;
}
```

tamanho

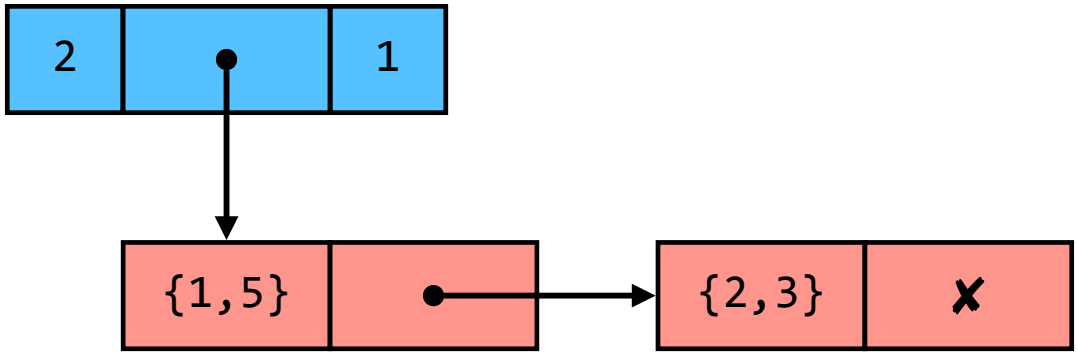



```
int tamanho(poligonal *l) {
  int r = 0;
  for (lponto aux = l->pontos; aux != NULL; aux = aux->prox) r++;
  return r;
}
```

Poligonal com lista ligada

```
typedef struct lponto_no {
  ponto ponto;
  struct lponto_no *prox;
} *lponto;

typedef struct {
  int tamanho;
  lponto pontos;
  cor cor;
} poligonal;
```



tamanho

```
int tamanho(poligonal *l) {
  return l->tamanho;
}
```

Aula 15

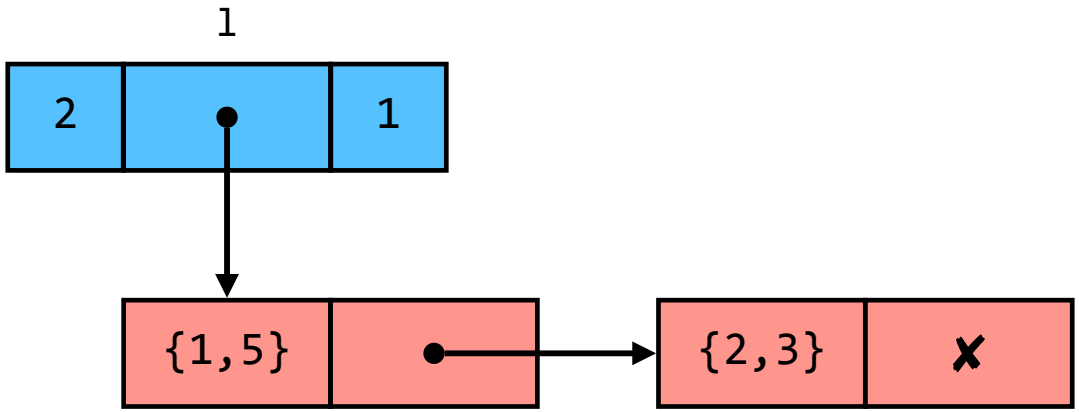
comprimento

```
float comprimento(poligonal *l) {
  float r = 0;
  if (l->pontos == NULL) return r;
  for (lponto aux = l->pontos; aux->prox != NULL; aux = aux->prox)
    r += dist(aux->ponto, aux->prox->ponto);
  return r;
}
```

estende

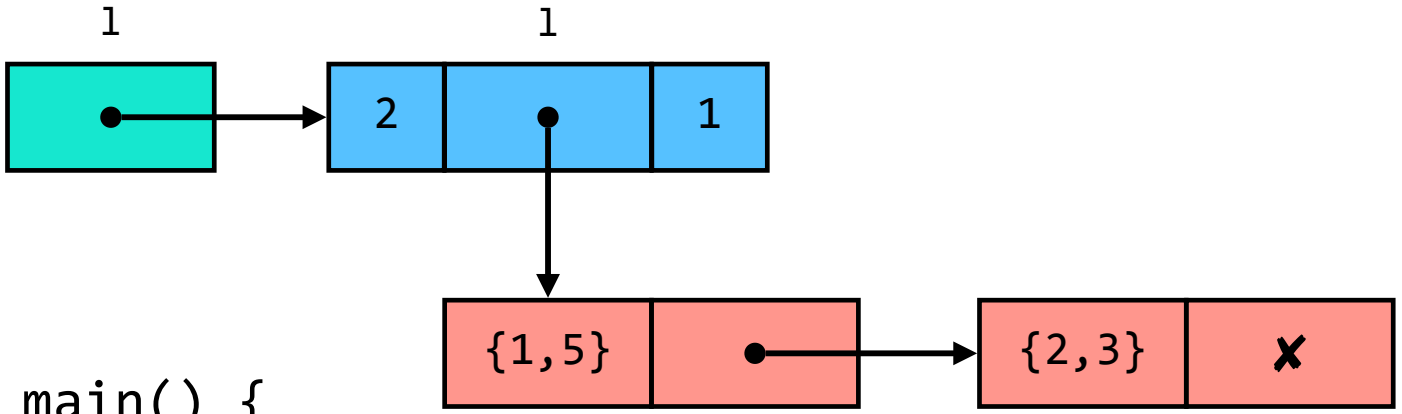
```
int estende(poligonal *l, ponto p) {
  …
}
```

estende



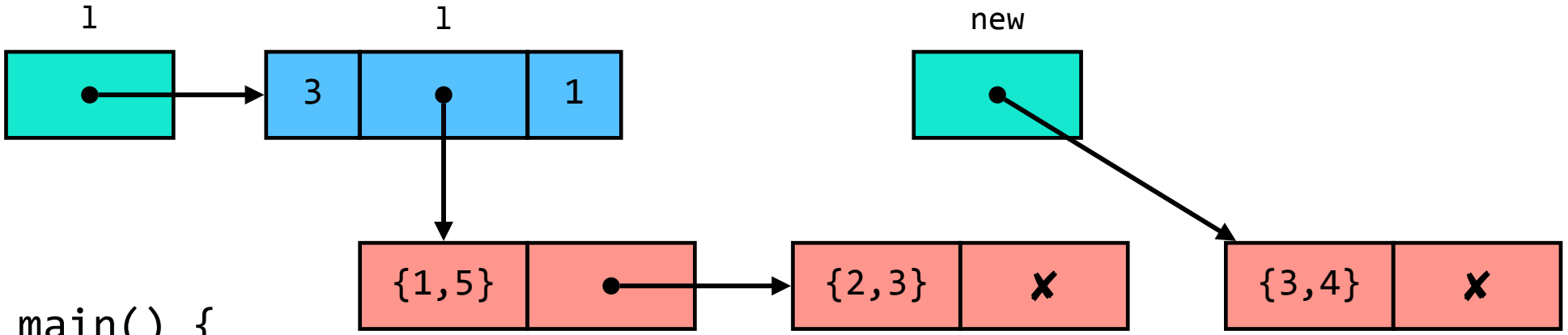

```
int main() {
  ponto p = {3,4};
  poligonal l = …;
  estende(&l, p);
  return 0;
}
```

estende



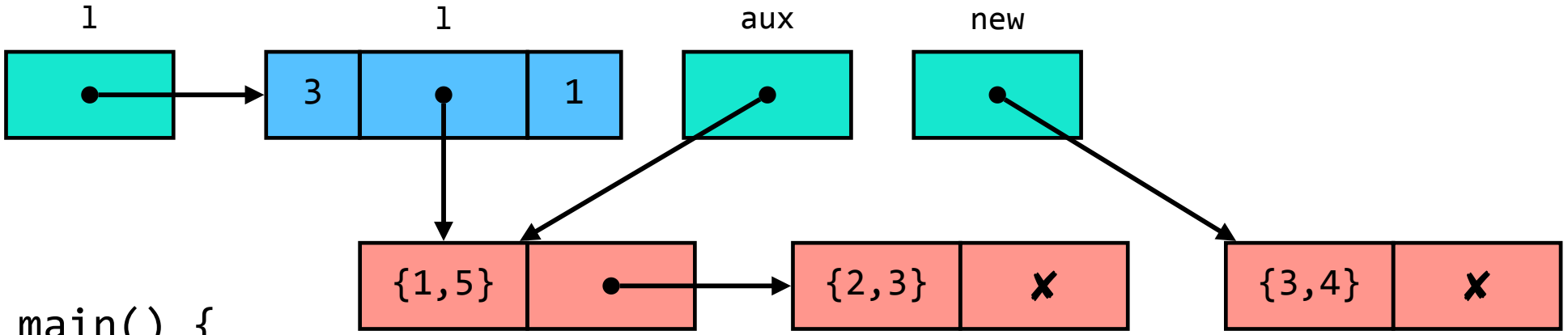

```
int main() {
  ponto p = {3,4};
  poligonal l = …;
  estende(&l, p);
  return 0;
}
```

estende



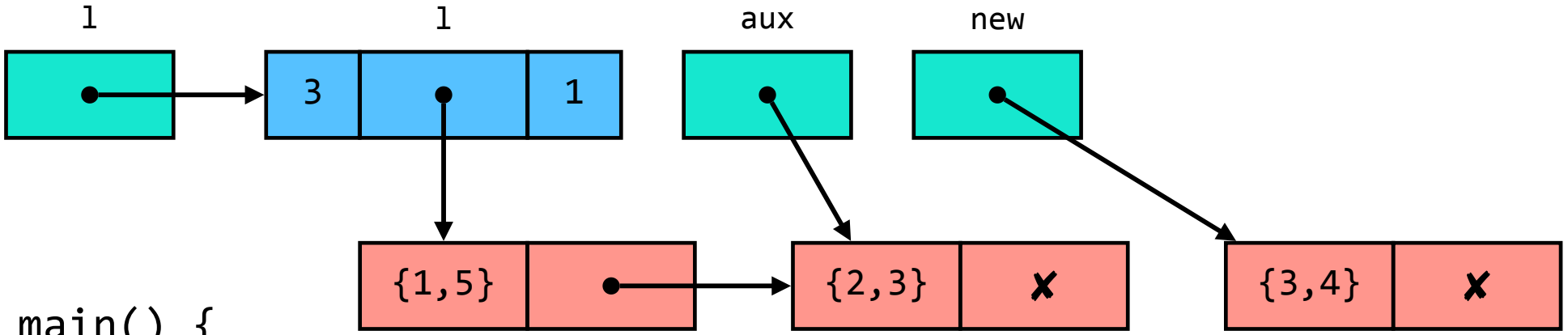

```
int main() {
  ponto p = {3,4};
  poligonal l = …;
  estende(&l, p);
  return 0;
}
```

estende



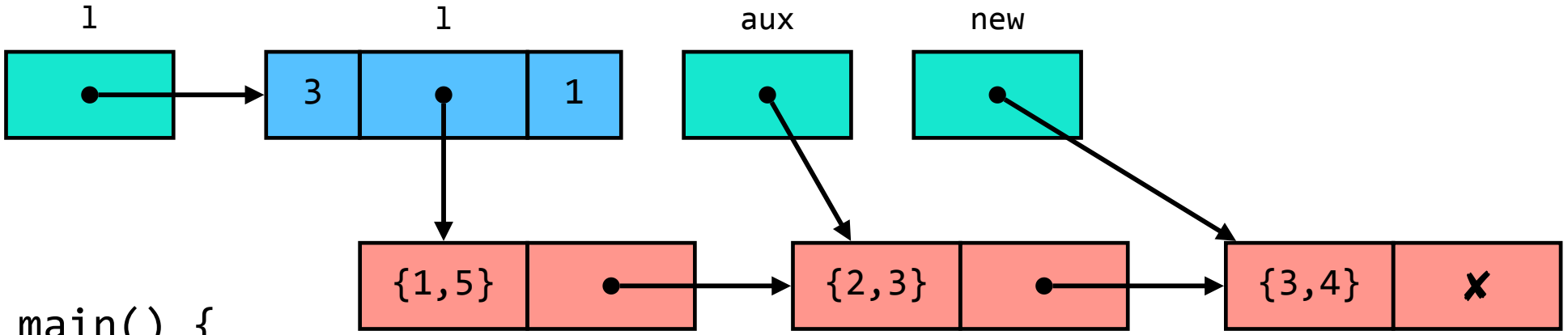

```
int main() {
  ponto p = {3,4};
  poligonal l = …;
  estende(&l, p);
  return 0;
}
```

estende



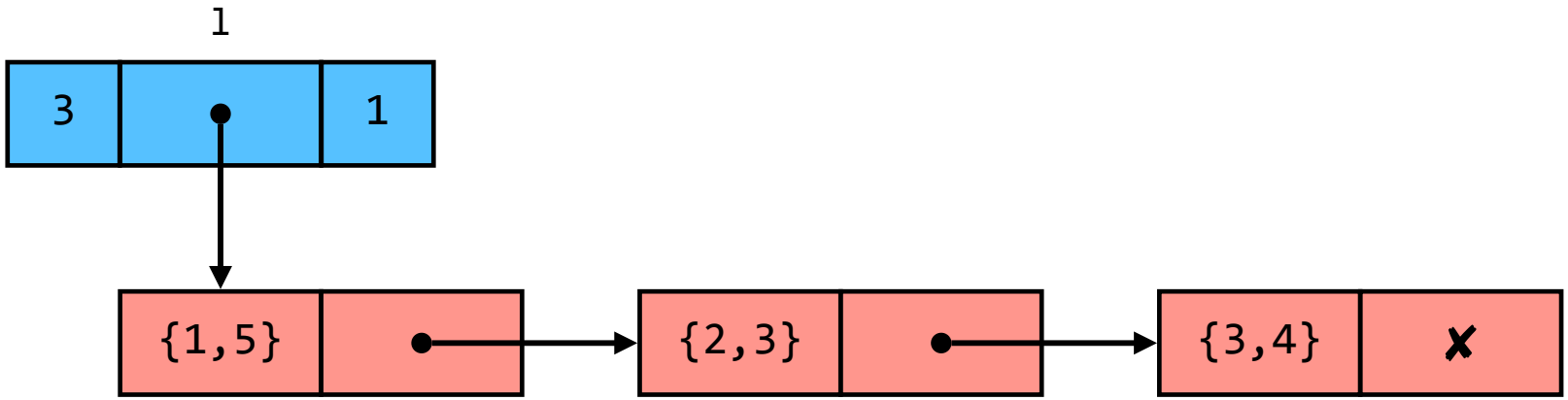

```
int main() {
  ponto p = {3,4};
  poligonal l = …;
  estende(&l, p);
  return 0;
}
```

estende



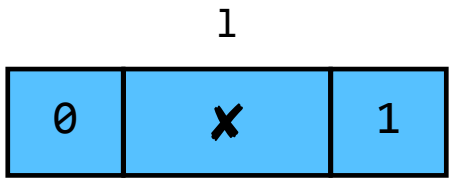

```
int main() {
  ponto p = {3,4};
  poligonal l = …;
  estende(&l, p);
  return 0;
}
```

estende



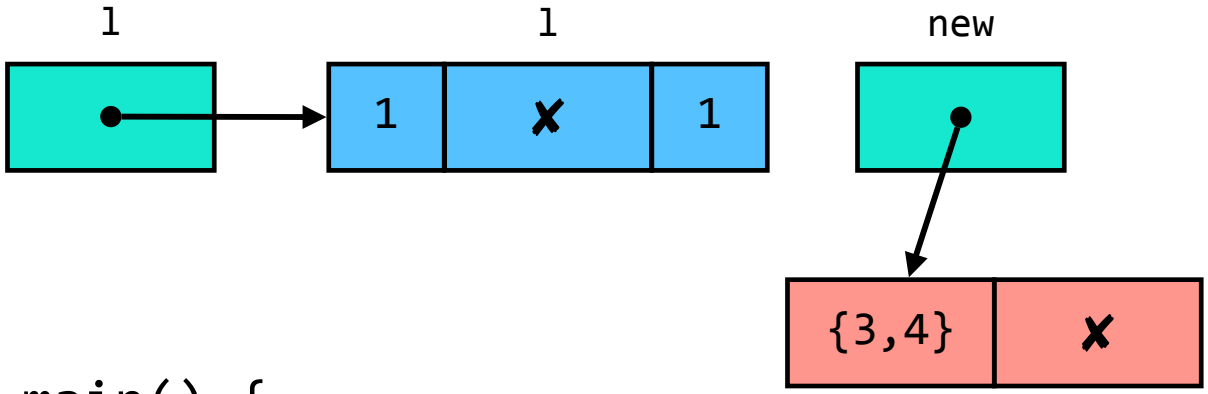

```
int main() {
  ponto p = {3,4};
  poligonal l = …;
  estende(&l, p);
  return 0;
}
```

estende



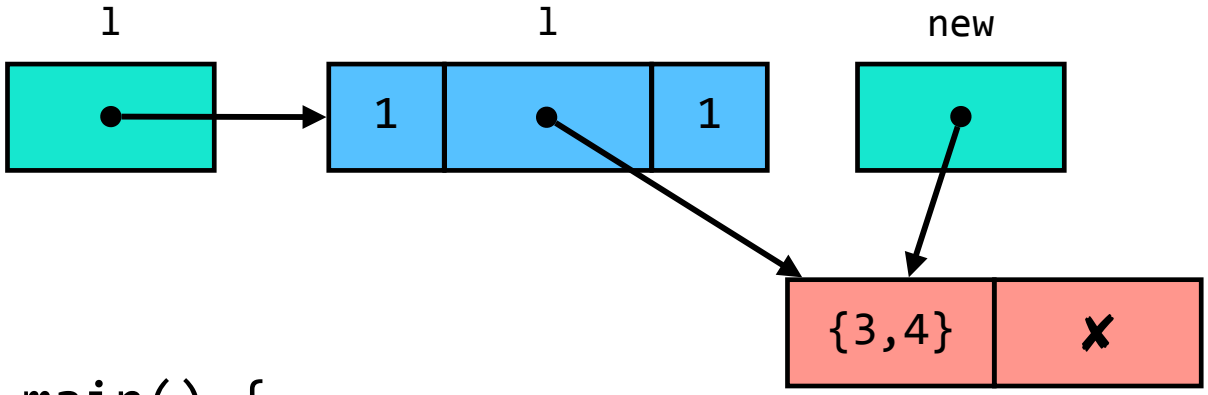

```
int main() {
  ponto p = {3,4};
  poligonal l = {0, NULL};
  estende(&l, p);
  return 0;
}
```

estende



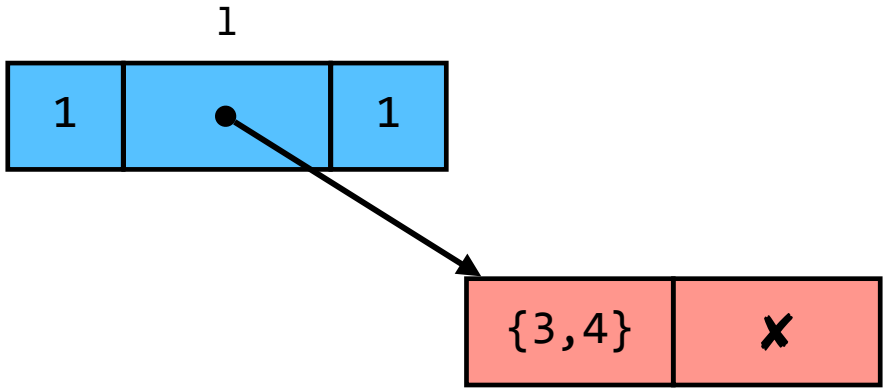

```
int main() {
  ponto p = {3,4};
  poligonal l = {0, NULL};
  estende(&l, p);
  return 0;
}
```

estende




```
int main() {
  ponto p = {3,4};
  poligonal l = {0, NULL};
  estende(&l, p);
  return 0;
}
```

estende




```
int main() {
  ponto p = {3,4};
  poligonal l = {0, NULL};
  estende(&l, p);
  return 0;
}
```

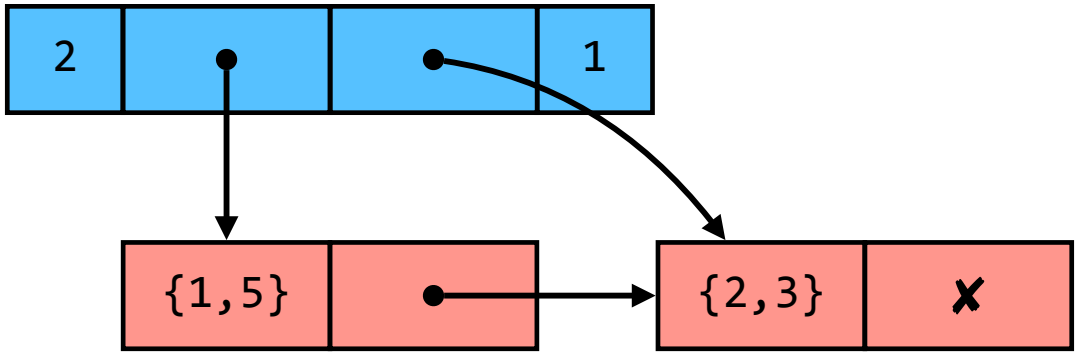
estende

```
int estende(poligonal *l, ponto p) {
  lponto new = malloc(sizeof(struct lponto_no));
  if (new == NULL) return 1;
  new->ponto = p;
  new->prox = NULL;
  l->tamanho++;
  if (l->pontos == NULL) l->pontos = new;
  else {
    lponto aux;
    for (aux = l->pontos; aux->prox != NULL; aux = aux->prox);
    aux->prox = new;
  }
  return 0;
}
```

Poligonal com lista ligada

```
typedef struct lponto_no {
  ponto ponto;
  struct lponto_no *prox;
} *lponto;

typedef struct {
  int tamanho;
  lponto pontos;
  lponto ultimo;
  cor cor;
} poligonal;
```



estende

```
int estende(poligonal *l, ponto p) {
  lponto new = malloc(sizeof(struct lponto_no));
  if (new == NULL) return 1;
  new->ponto = p;
  new->prox = NULL;
  l->tamanho++;
  if (l->pontos == NULL) l->pontos = new;
  else l->ultimo->prox = new;
  l->ultimo = new;
  return 0;
}
```

aloca e liberta

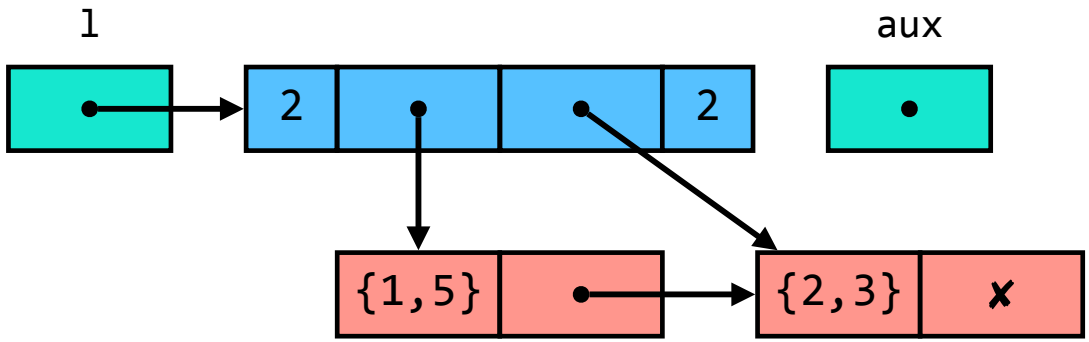
```
int aloca(poligonal *l, cor c) {
  l->tamanho = 0;
  l->pontos = NULL;
  l->ultimo = NULL;
  l->cor = c;
  return 0;
}

void liberta(poligonal *l) {
  lponto aux;
  while (l->pontos != NULL) {
    aux = l->pontos;
    l->pontos = l->pontos->prox;
    free(aux);
  }
}
```

aloca e liberta

```
int aloca(poligonal *l, cor c) {
  l->tamanho = 0;
  l->pontos = NULL;
  l->ultimo = NULL;
  l->cor = c;
  return 0;
}

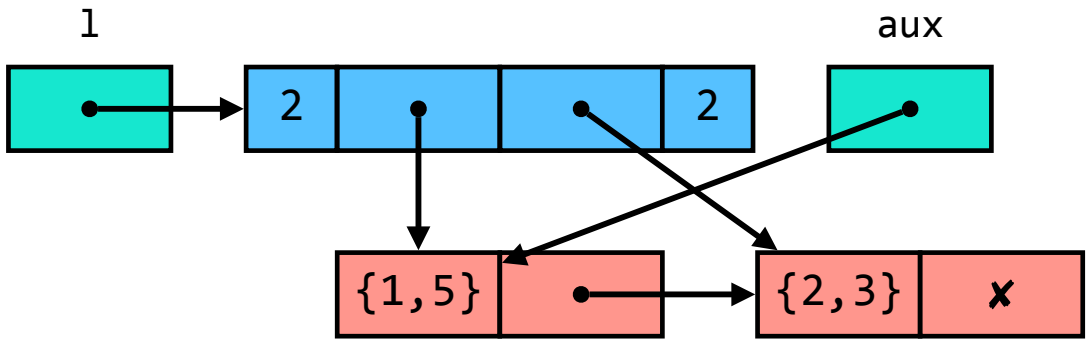
void liberta(poligonal *l) {
  lponto aux;
  while (l->pontos != NULL) {
    aux = l->pontos;
    l->pontos = l->pontos->prox;
    free(aux);
  }
}
```



aloca e liberta

```
int aloca(poligonal *l, cor c) {
  l->tamanho = 0;
  l->pontos = NULL;
  l->ultimo = NULL;
  l->cor = c;
  return 0;
}

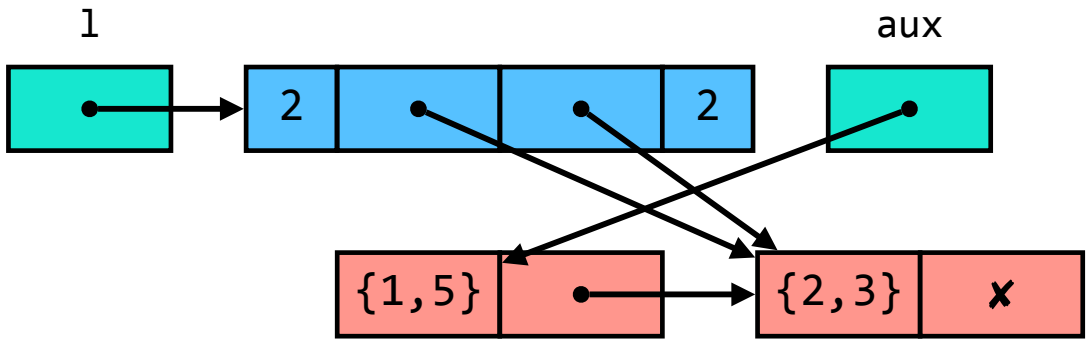
void liberta(poligonal *l) {
  lponto aux;
  while (l->pontos != NULL) {
    aux = l->pontos;
    l->pontos = l->pontos->prox;
    free(aux);
  }
}
```



aloca e liberta

```
int aloca(poligonal *l, cor c) {
  l->tamanho = 0;
  l->pontos = NULL;
  l->ultimo = NULL;
  l->cor = c;
  return 0;
}

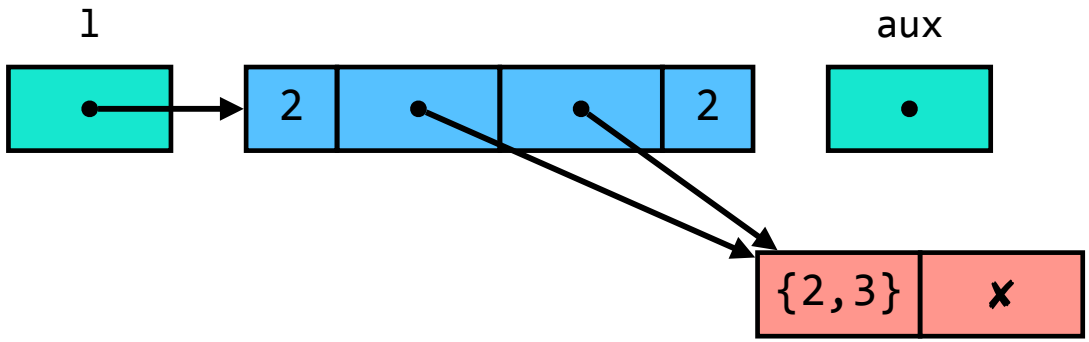
void liberta(poligonal *l) {
  lponto aux;
  while (l->pontos != NULL) {
    aux = l->pontos;
    l->pontos = l->pontos->prox;
    free(aux);
  }
}
```



aloca e liberta

```
int aloca(poligonal *l, cor c) {
  l->tamanho = 0;
  l->pontos = NULL;
  l->ultimo = NULL;
  l->cor = c;
  return 0;
}

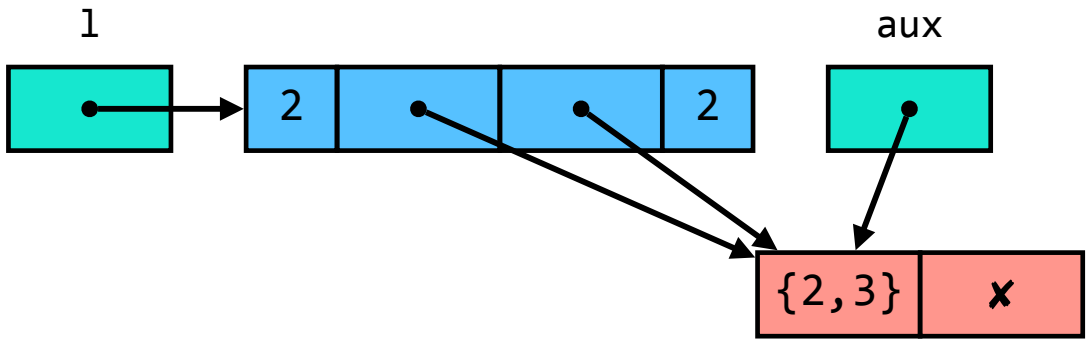
void liberta(poligonal *l) {
  lponto aux;
  while (l->pontos != NULL) {
    aux = l->pontos;
    l->pontos = l->pontos->prox;
    free(aux);
  }
}
```



aloca e liberta

```
int aloca(poligonal *l, cor c) {
  l->tamanho = 0;
  l->pontos = NULL;
  l->ultimo = NULL;
  l->cor = c;
  return 0;
}

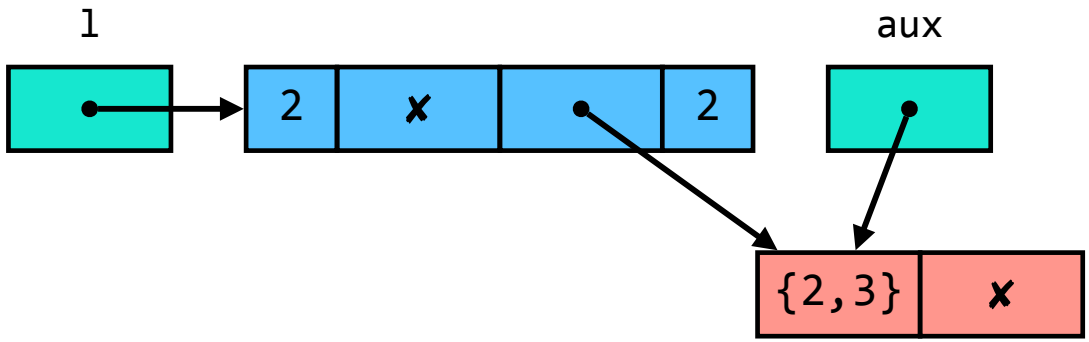
void liberta(poligonal *l) {
  lponto aux;
  while (l->pontos != NULL) {
    aux = l->pontos;
    l->pontos = l->pontos->prox;
    free(aux);
  }
}
```



aloca e liberta

```
int aloca(poligonal *l, cor c) {
  l->tamanho = 0;
  l->pontos = NULL;
  l->ultimo = NULL;
  l->cor = c;
  return 0;
}

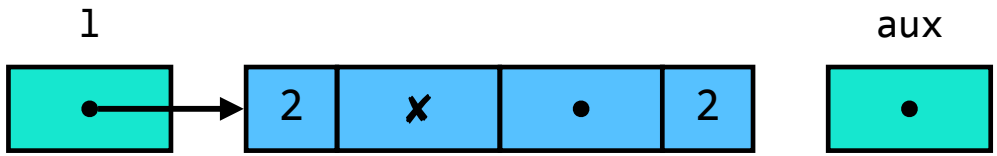
void liberta(poligonal *l) {
  lponto aux;
  while (l->pontos != NULL) {
    aux = l->pontos;
    l->pontos = l->pontos->prox;
    free(aux);
  }
}
```



aloca e liberta

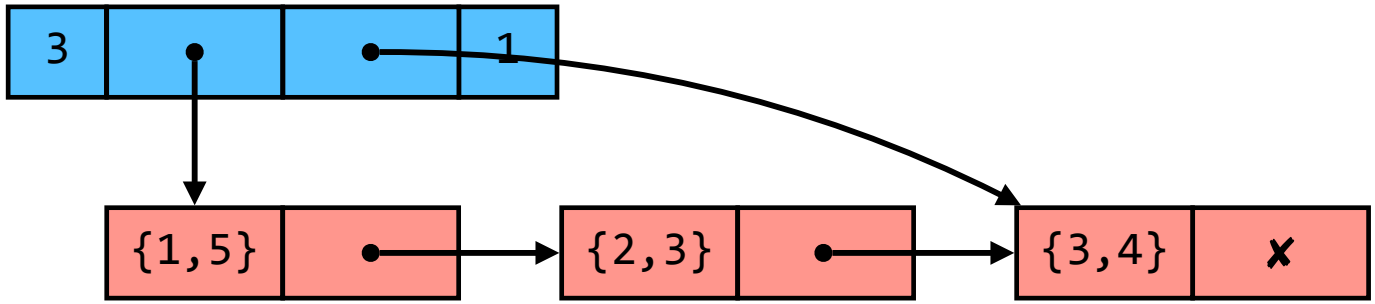
```
int aloca(poligonal *l, cor c) {
  l->tamanho = 0;
  l->pontos = NULL;
  l->ultimo = NULL;
  l->cor = c;
  return 0;
}

void liberta(poligonal *l) {
  lponto aux;
  while (l->pontos != NULL) {
    aux = l->pontos;
    l->pontos = l->pontos->prox;
    free(aux);
  }
}
```



Poligonal com lista ligada

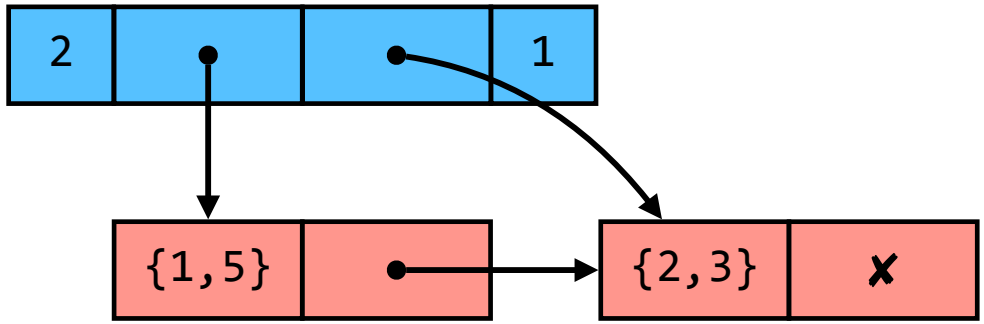
```
int main() {
  ponto a = {1,5}, b = {2,3}, c = {3,4};
  poligonal l;
  aloca(&l,GREEN);
  estende(&l,a);
  estende(&l,b);
  estende(&l,c);
  printf("%.1f",comprimento(&l));
  liberta(&l);
  return 0;
}
```



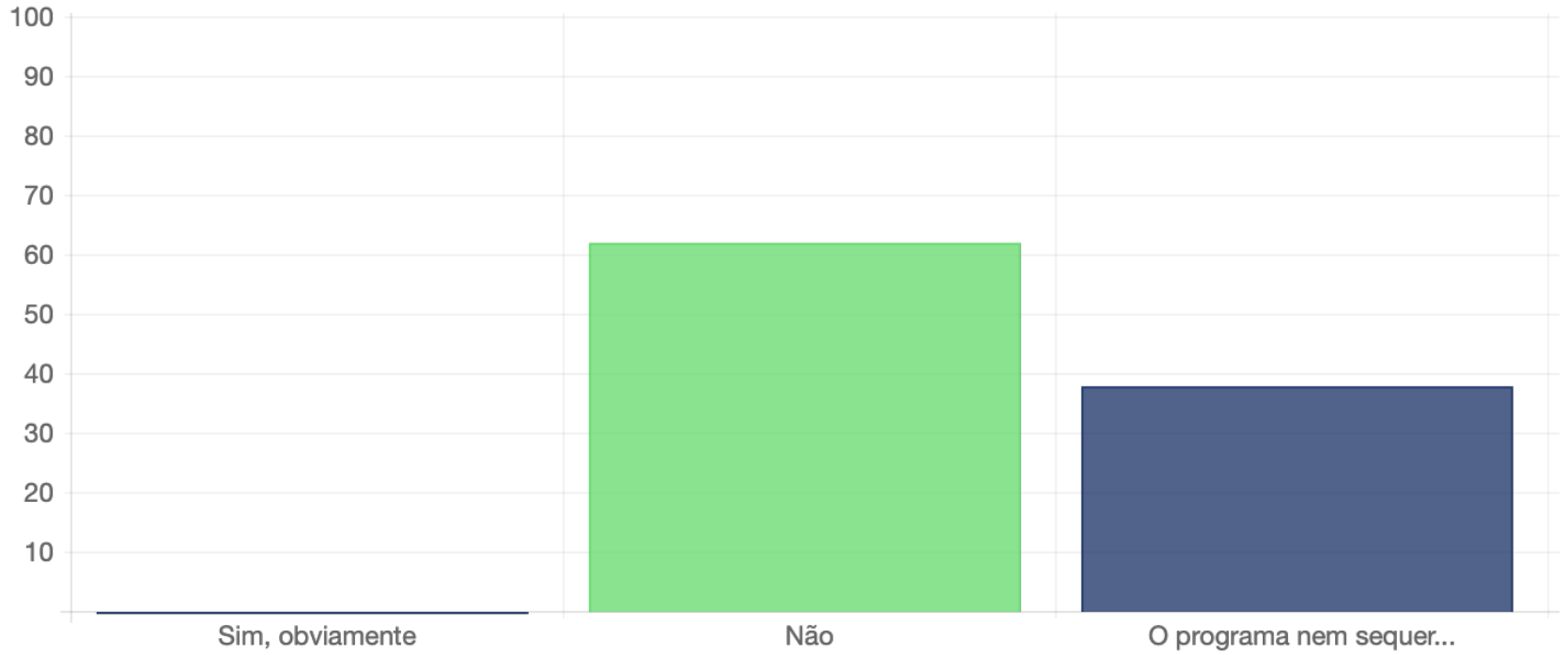
#20 É verdade que `tamanho(&l) == tamanho(&l)`?

```
int tamanho(poligonal *l) {
  int r = 0;
  while (l->pontos != NULL) {
    l->pontos = l->pontos->prox;
    r++;
  }
  return r;
}

int main() {
  poligonal l = …;
  printf("%d\n",tamanho(&l) == tamanho(&l));
  return 0;
}
```

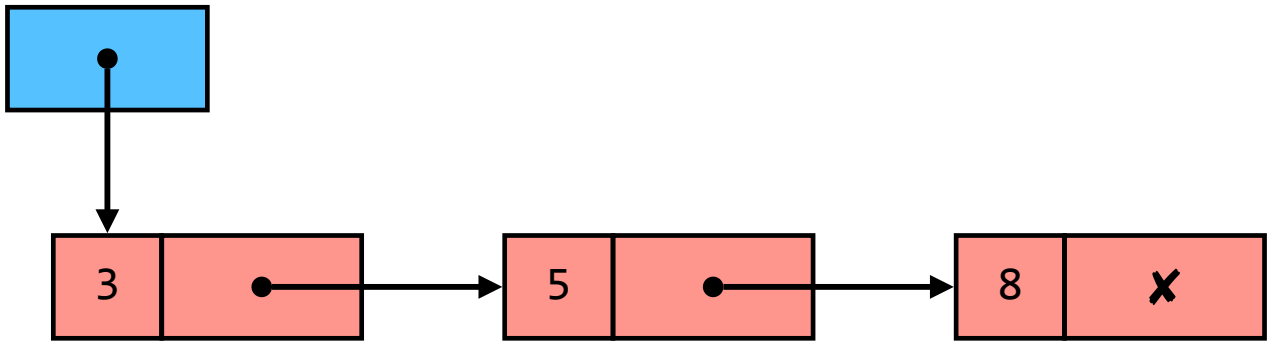


#20 É verdade que `tamanho(&l) == tamanho(&l)`?



Aula 16

Listas ligadas de inteiros

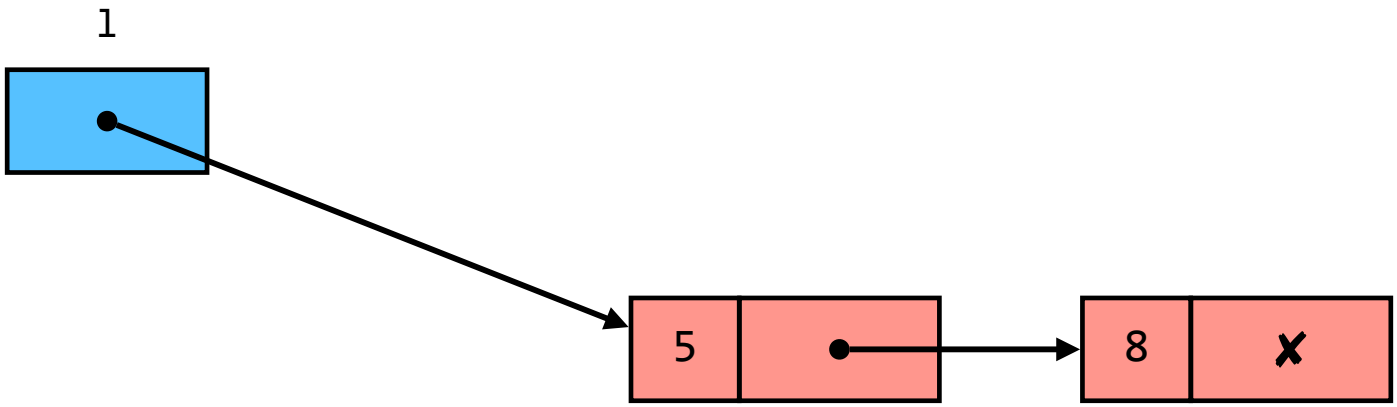



```
typedef struct lint_no {
  int valor;
  struct lint_no *prox;
} *lint;
```

Inserção à cabeça

```
int cons(int x, lint *l) {
  lint new = malloc(sizeof(struct lint_no));
  if (new == NULL) return 1;
  new->valor = x;
  new->prox = l;
  *l = new;
  return 0;
}

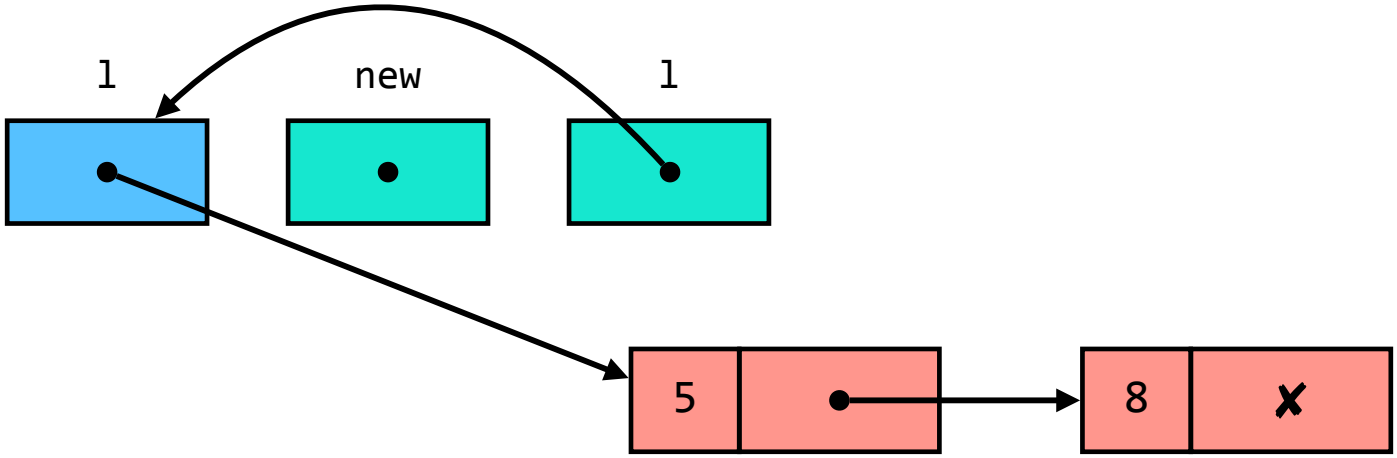
int main() {
  lint l = NULL;
  cons(8,&l);
  cons(5,&l);
  cons(3,&l);
  return 0;
}
```



Inserção à cabeça

```
int cons(int x, lint *l) {
  lint new = malloc(sizeof(struct lint_no));
  if (new == NULL) return 1;
  new->valor = x;
  new->prox = *l;
  *l = new;
  return 0;
}

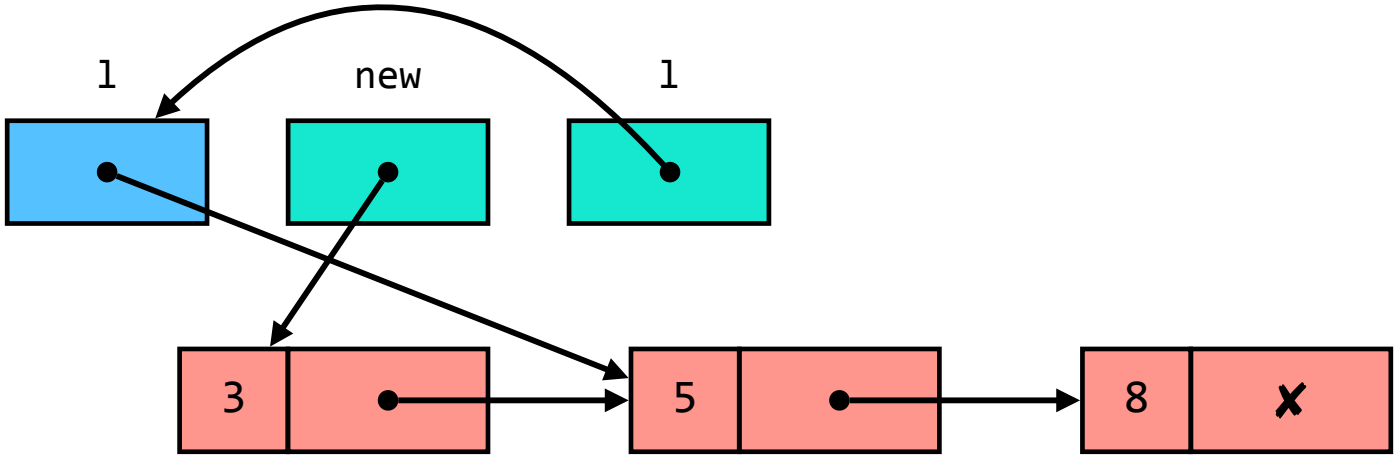
int main() {
  lint l = NULL;
  cons(8,&l);
  cons(5,&l);
  cons(3,&l);
  return 0;
}
```



Inserção à cabeça

```
int cons(int x, lint *l) {
  lint new = malloc(sizeof(struct lint_no));
  if (new == NULL) return 1;
  new->valor = x;
  new->prox = *l;
  *l = new;
  return 0;
}

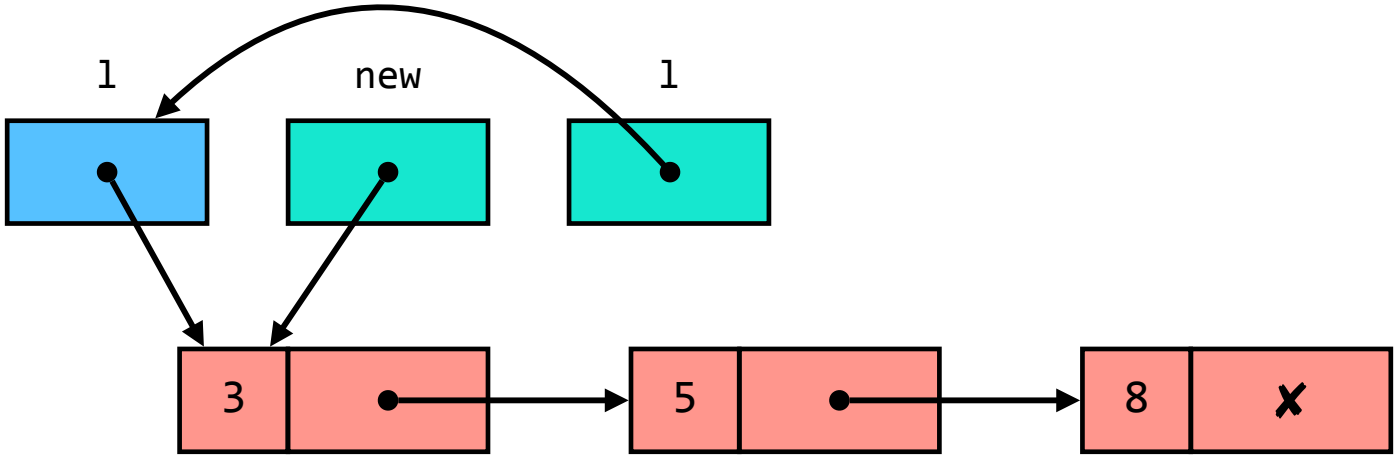
int main() {
  lint l = NULL;
  cons(8,&l);
  cons(5,&l);
  cons(3,&l);
  return 0;
}
```



Inserção à cabeça

```
int cons(int x, lint *l) {
  lint new = malloc(sizeof(struct lint_no));
  if (new == NULL) return 1;
  new->valor = x;
  new->prox = *l;
  *l = new;
  return 0;
}

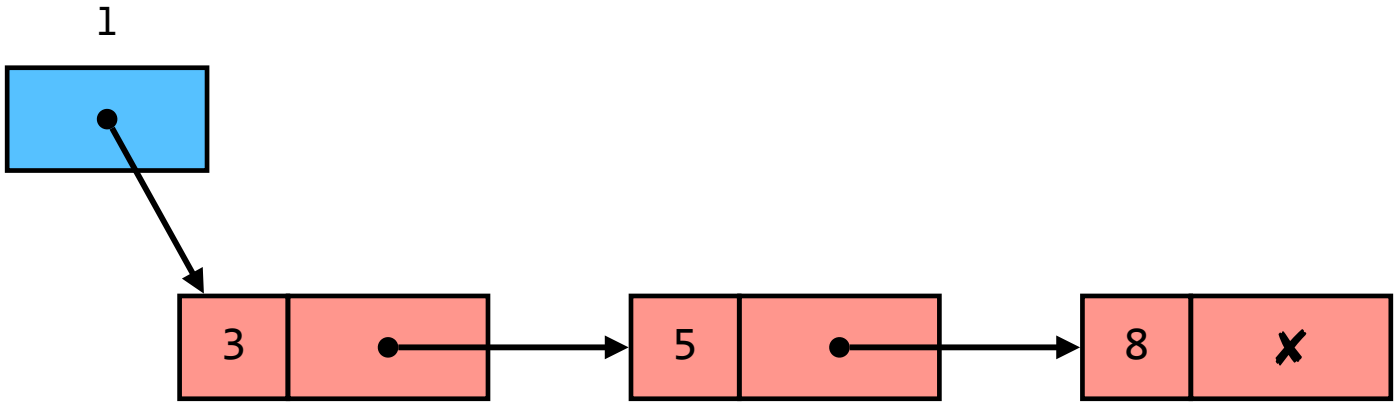
int main() {
  lint l = NULL;
  cons(8,&l);
  cons(5,&l);
  cons(3,&l);
  return 0;
}
```



Inserção à cabeça

```
int cons(int x, lint *l) {
  lint new = malloc(sizeof(struct lint_no));
  if (new == NULL) return 1;
  new->valor = x;
  new->prox = *l;
  *l = new;
  return 0;
}

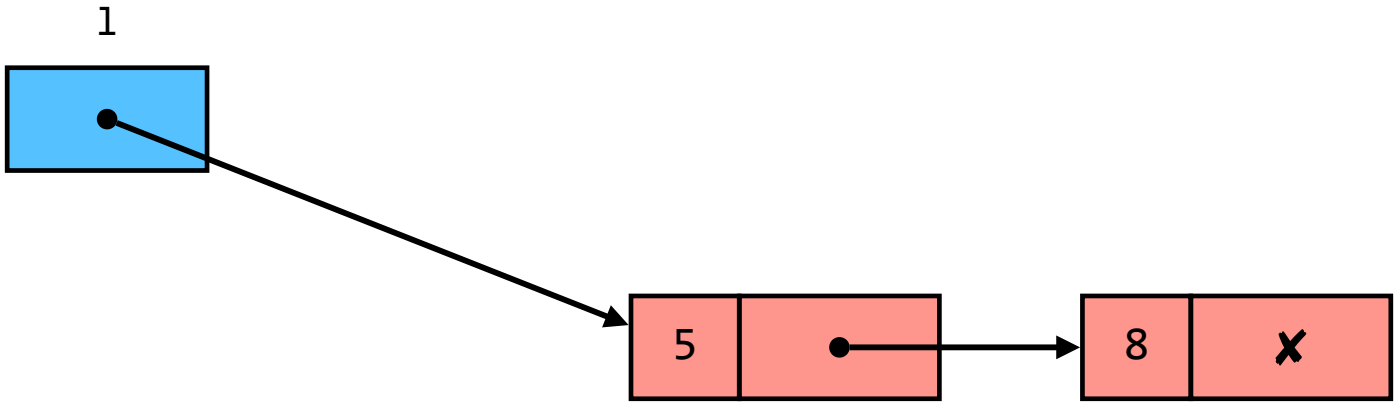
int main() {
  lint l = NULL;
  cons(8,&l);
  cons(5,&l);
  cons(3,&l);
  return 0;
}
```



Inserção à cabeça

```
lint cons(int x, lint l) {
  lint new = malloc(sizeof(struct lint_no));
  new->valor = x;
  new->prox = l;
  return new;
}

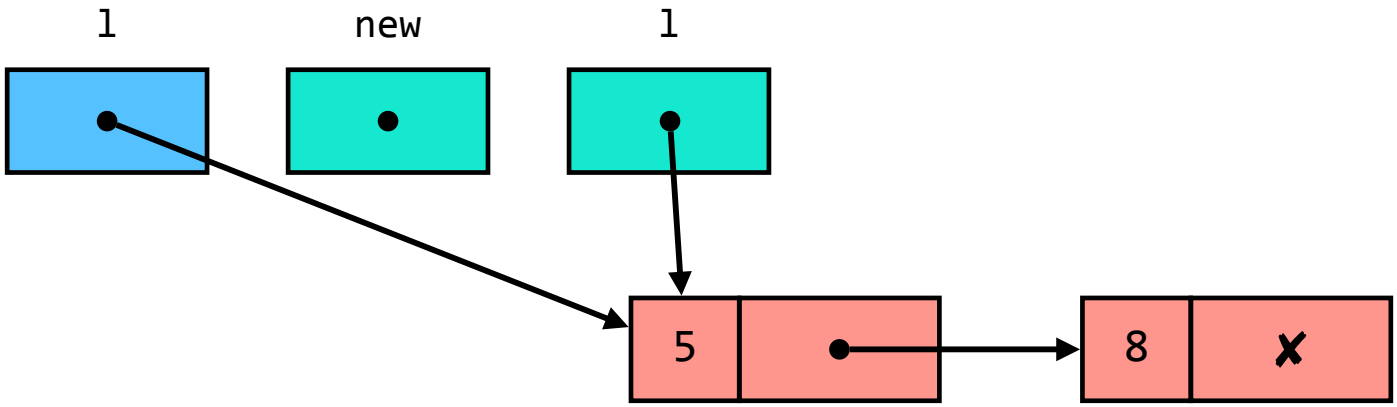
int main() {
  lint l = NULL;
  l = cons(8,l);
  l = cons(5,l);
  l = cons(3,l);
  return 0;
}
```



Inserção à cabeça

```
lint cons(int x, lint l) {
  lint new = malloc(sizeof(struct lint_no));
  new->valor = x;
  new->prox = l;
  return new;
}

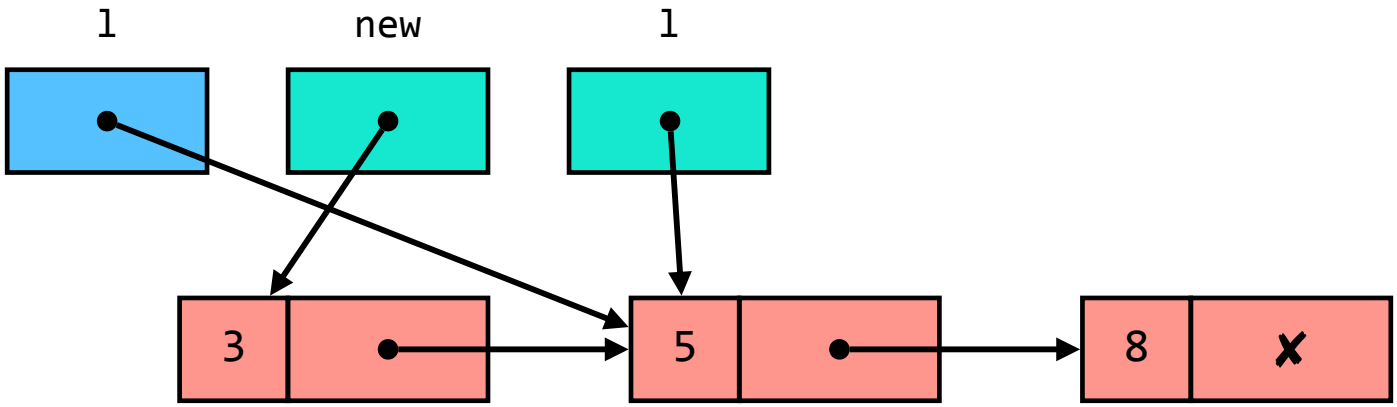
int main() {
  lint l = NULL;
  l = cons(8,l);
  l = cons(5,l);
  l = cons(3,l);
  return 0;
}
```



Inserção à cabeça

```
lint cons(int x, lint l) {
  lint new = malloc(sizeof(struct lint_no));
  new->valor = x;
  new->prox = l;
  return new;
}

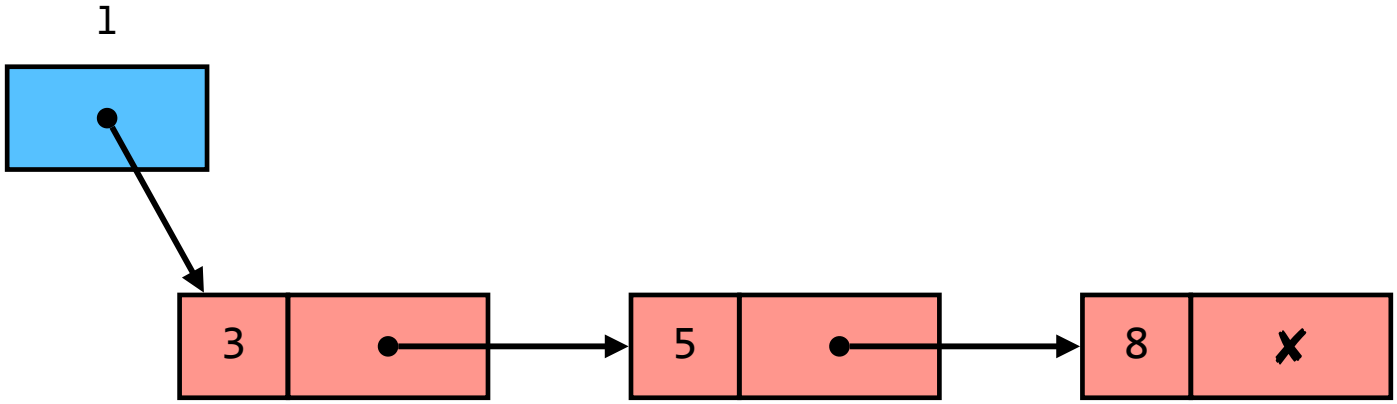
int main() {
  lint l = NULL;
  l = cons(8,l);
  l = cons(5,l);
  l = cons(3,l);
  return 0;
}
```



Inserção à cabeça

```
lint cons(int x, lint l) {
  lint new = malloc(sizeof(struct lint_no));
  new->valor = x;
  new->prox = l;
  return new;
}

int main() {
  lint l = NULL;
  l = cons(8,l);
  l = cons(5,l);
  l = cons(3,l);
  return 0;
}
```



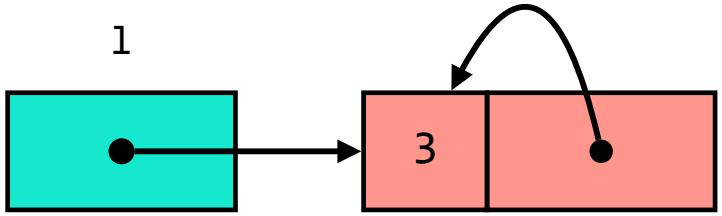
Disclaimer

#22 Como criar esta “lista”?

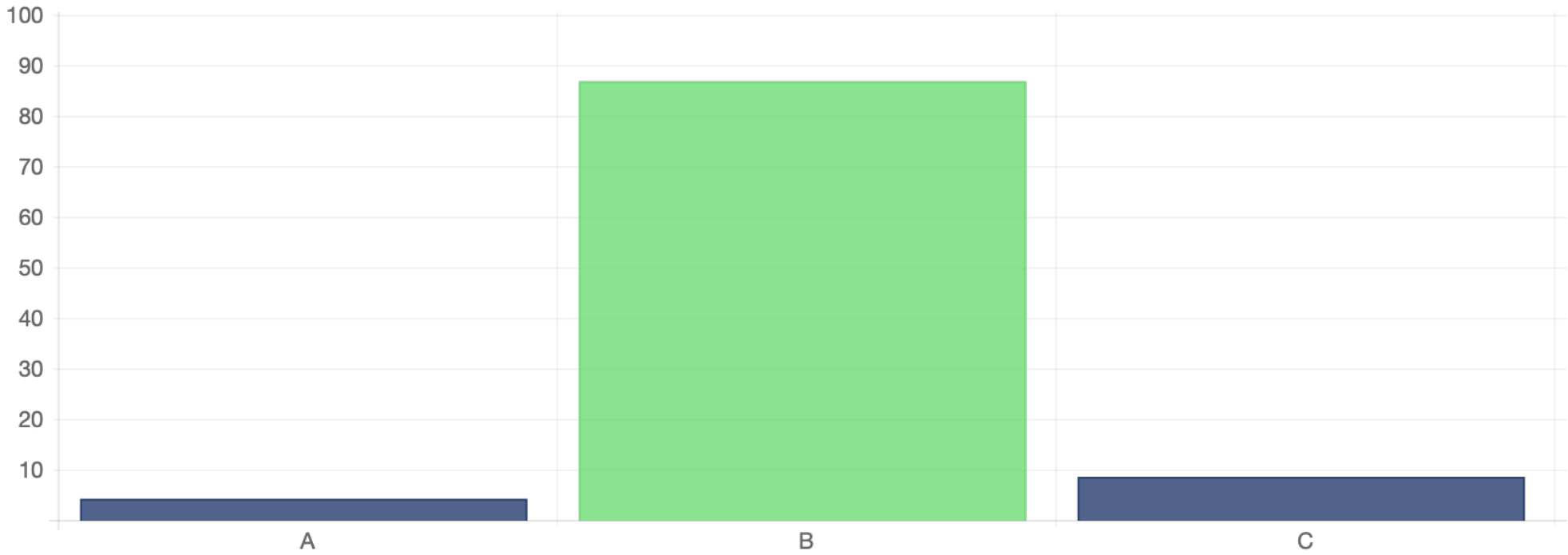
```
lint A() {
  lint l = cons(3, l);
  return l;
}

lint B() {
  lint l = cons(3, NULL);
  l->prox = l;
  return l;
}

lint C() {
  lint l = cons(3, NULL);
  l = l->prox;
  return l;
}
```



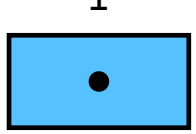
#22 Como criar esta “lista”?



Criação a partir de array

```
lint fromArray(int a[], int N) {
  lint l = NULL;
  for (int i = N-1; i >= 0; i--) l = cons(a[i], l);
  return l;
}

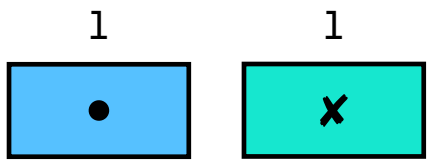
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  return 0;
}
```



Criação a partir de array

```
lint fromArray(int a[], int N) {
  lint l = NULL;
  for (int i = N-1; i >= 0; i--) l = cons(a[i], l);
  return l;
}

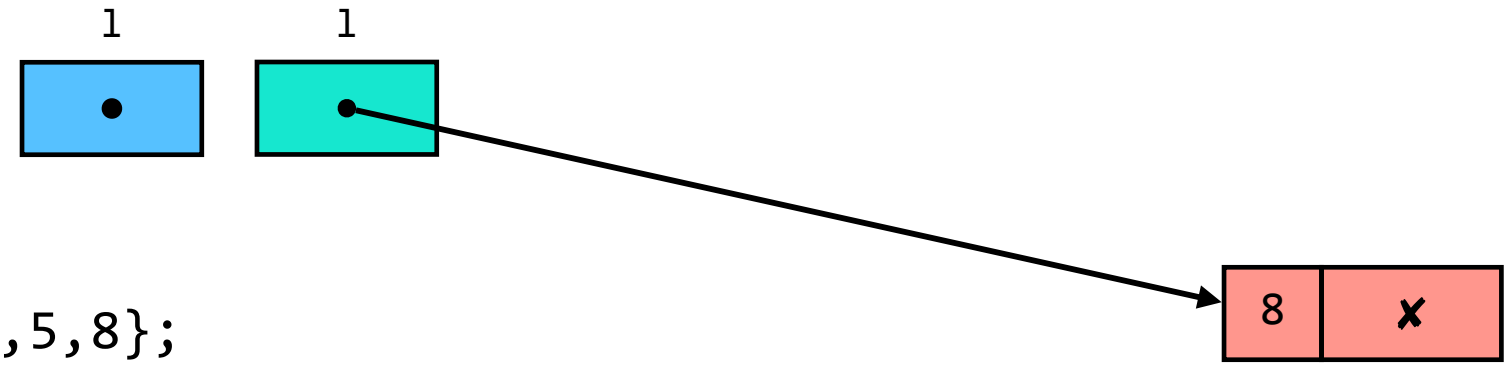
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  return 0;
}
```



Criação a partir de array

```
lint fromArray(int a[], int N) {
  lint l = NULL;
  for (int i = N-1; i >= 0; i--) l = cons(a[i], l);
  return l;
}

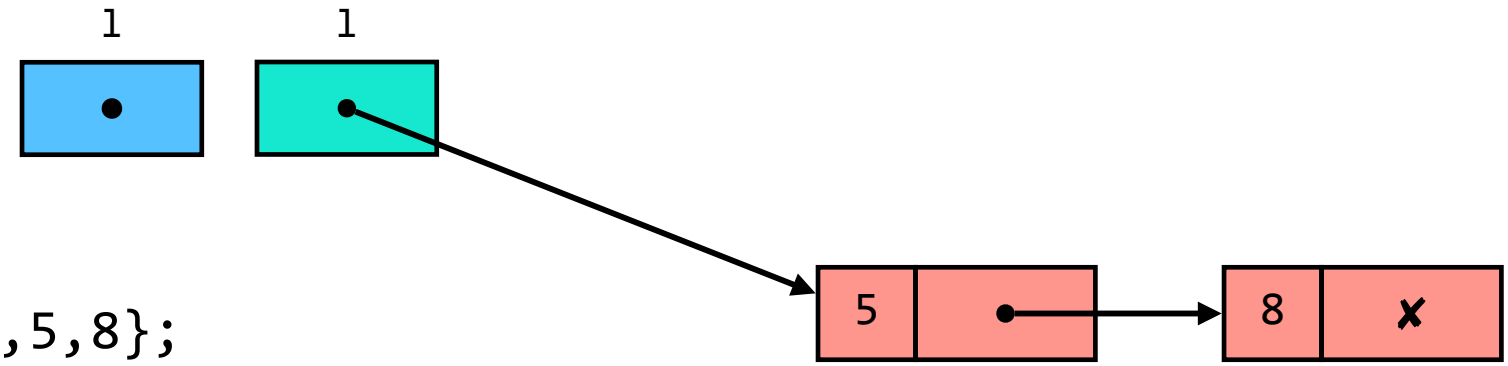
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  return 0;
}
```



Criação a partir de array

```
lint fromArray(int a[], int N) {
  lint l = NULL;
  for (int i = N-1; i >= 0; i--) l = cons(a[i], l);
  return l;
}

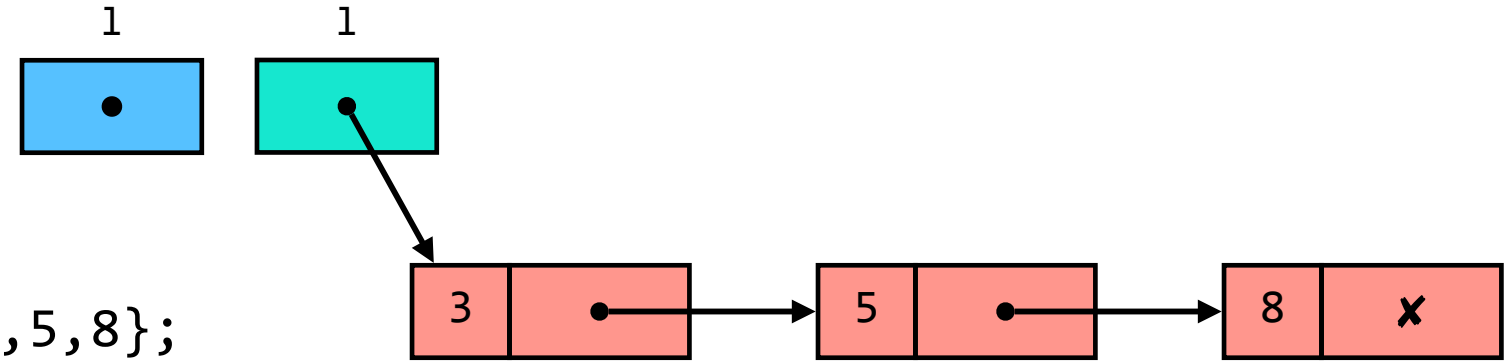
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  return 0;
}
```



Criação a partir de array

```
lint fromArray(int a[], int N) {
  lint l = NULL;
  for (int i = N-1; i >= 0; i--) l = cons(a[i], l);
  return l;
}

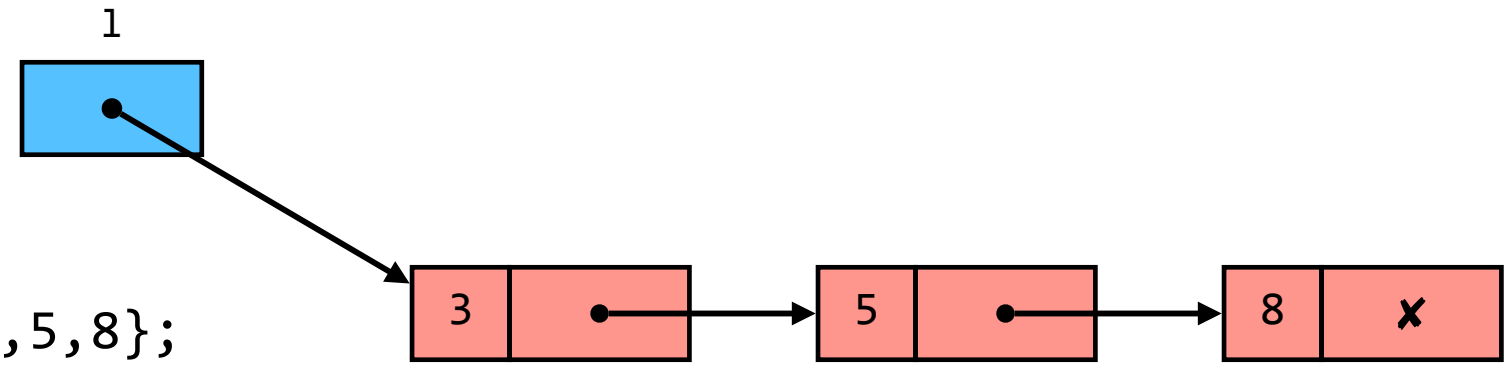
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  return 0;
}
```



Criação a partir de array

```
lint fromArray(int a[], int N) {
  lint l = NULL;
  for (int i = N-1; i >= 0; i--) l = cons(a[i], l);
  return l;
}

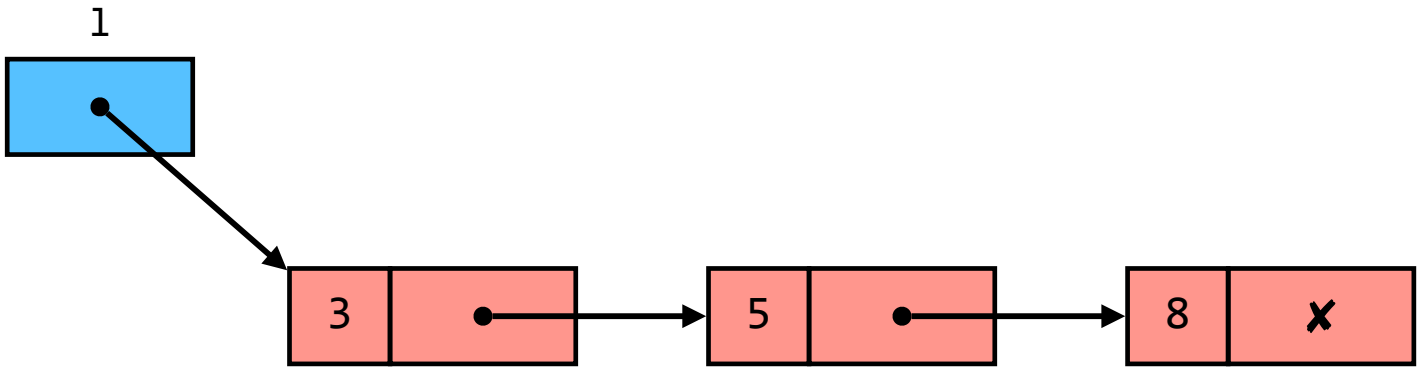
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  return 0;
}
```



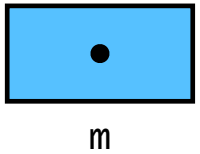
Duplicação

```
lint clone(lint l) {
  …
}
```

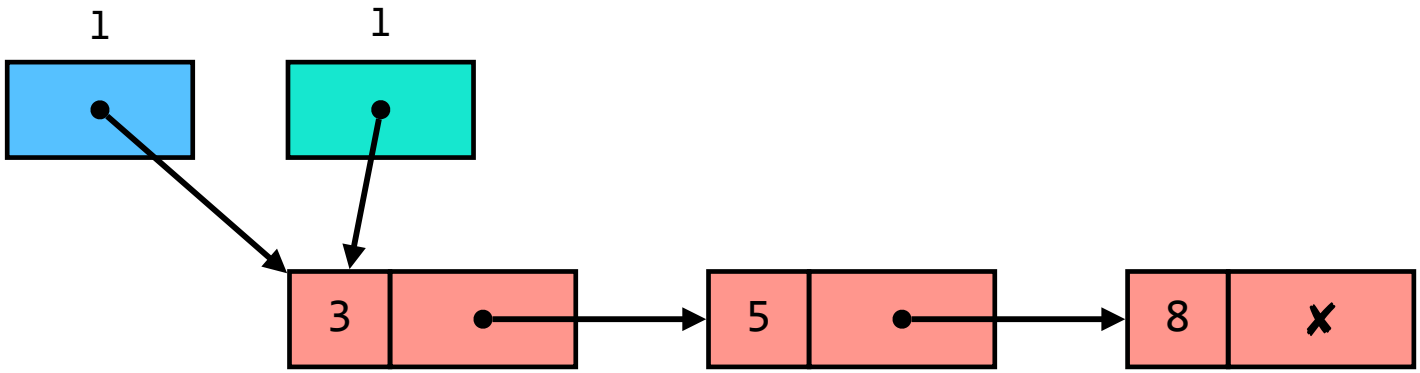
Duplicação



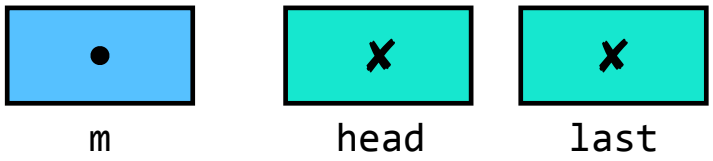

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  lint m = clone(l);
  return 0;
}
```



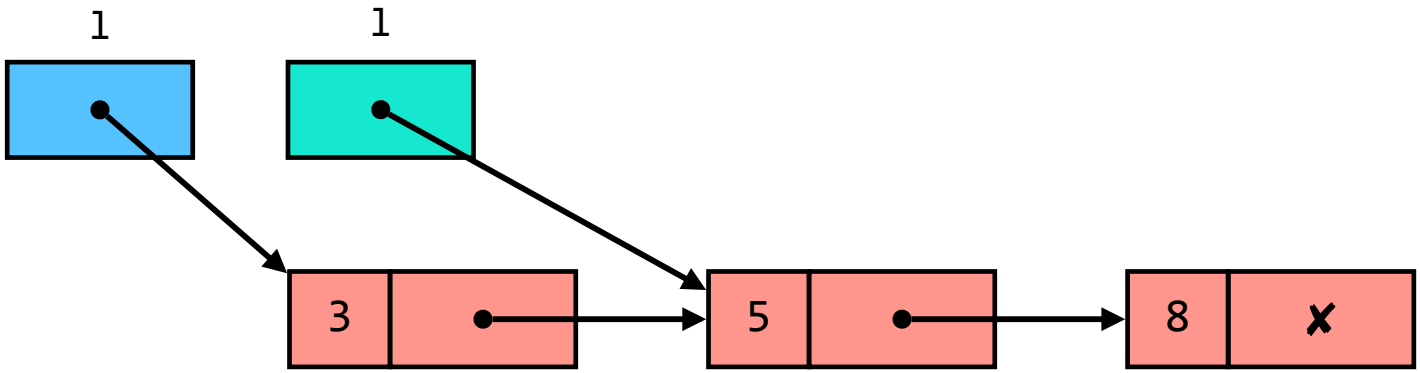
Duplicação



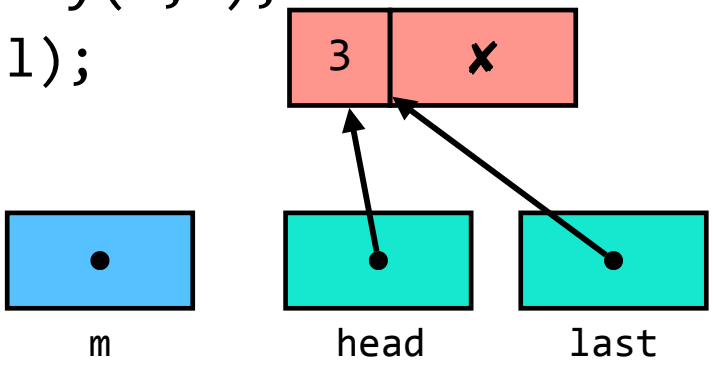

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  lint m = clone(l);
  return 0;
}
```



Duplicação

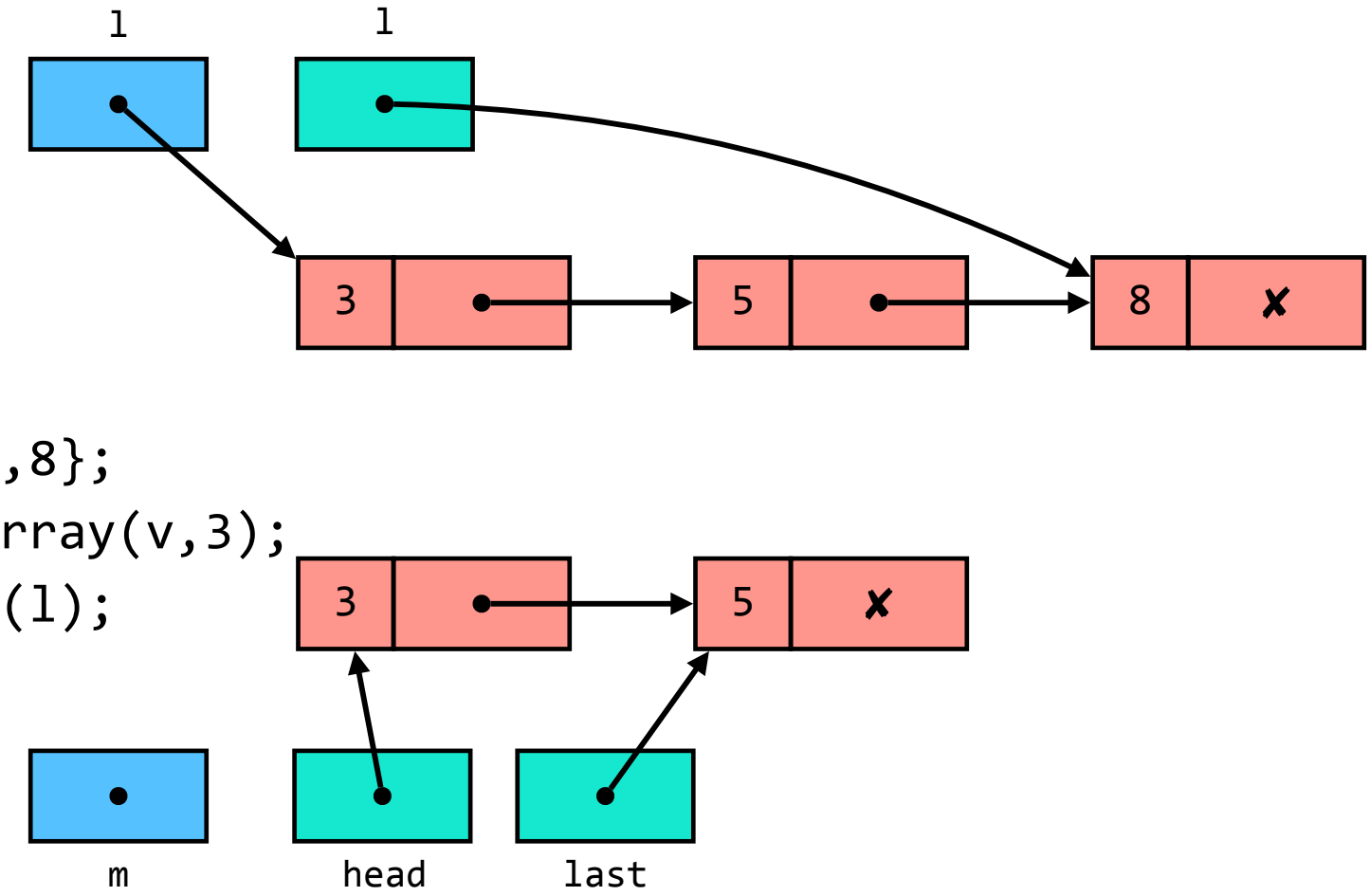



```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  lint m = clone(l);
  return 0;
}
```



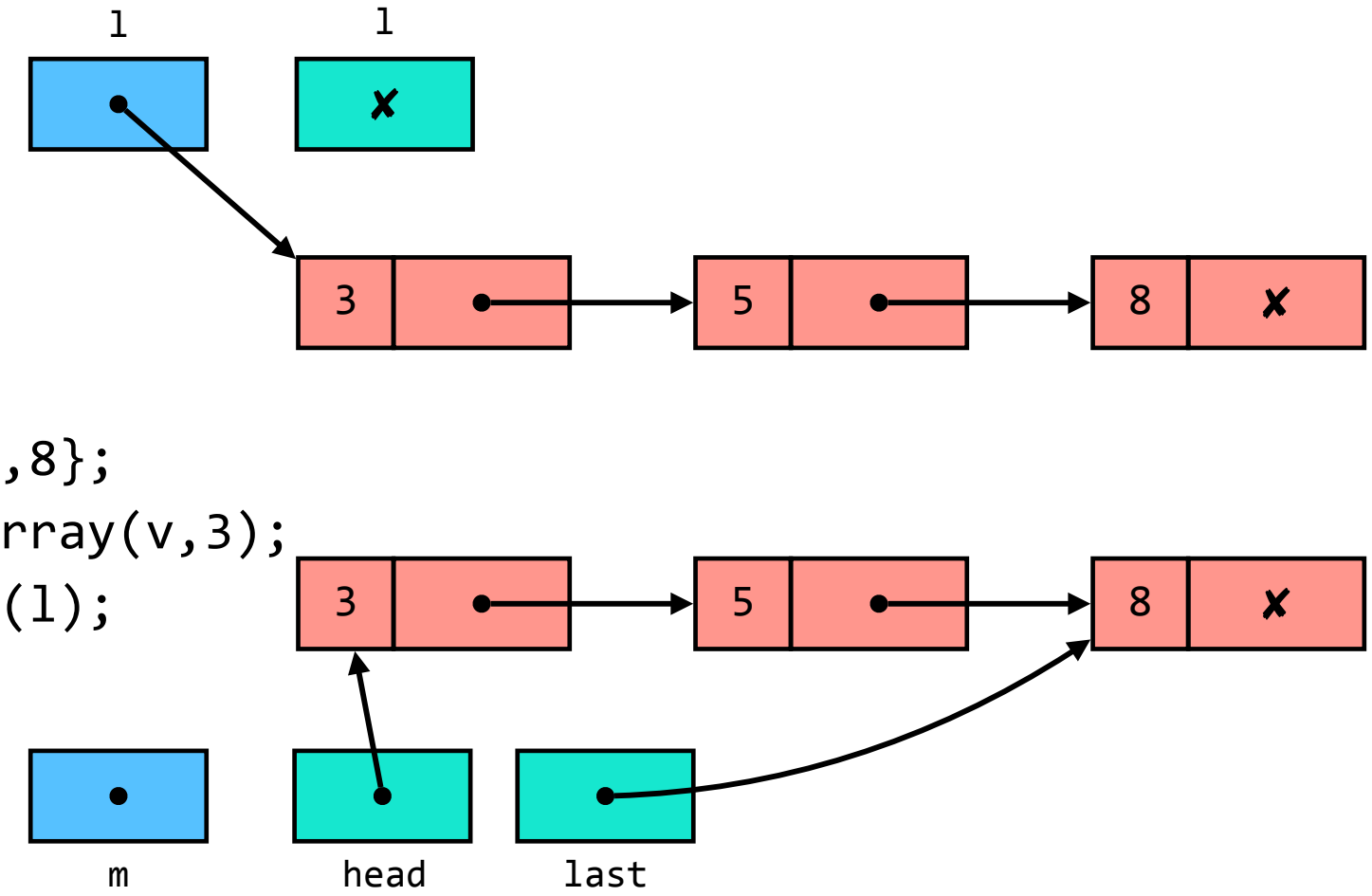
Duplicação

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  lint m = clone(l);
  return 0;
}
```



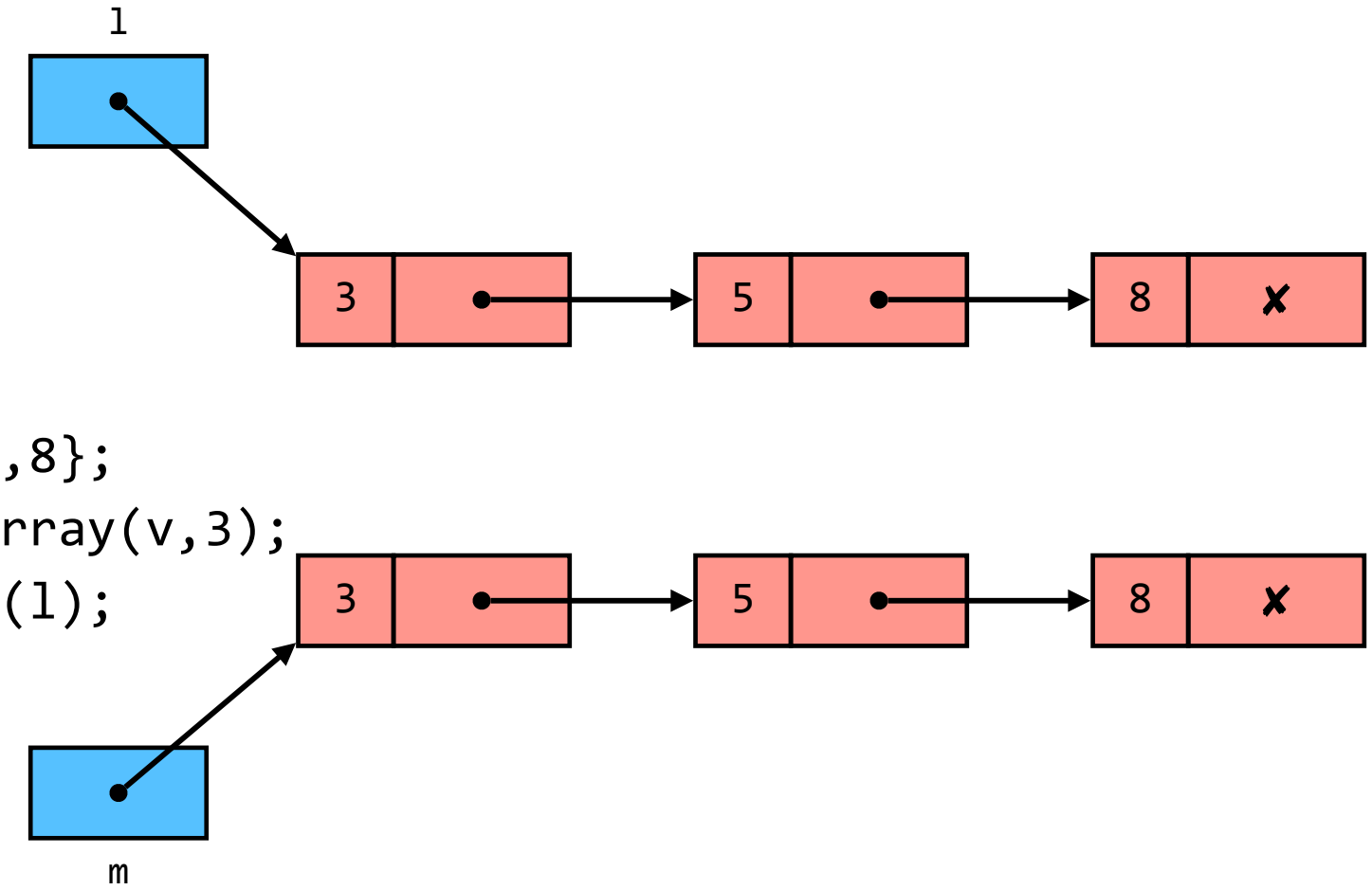
Duplicação

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  lint m = clone(l);
  return 0;
}
```



Duplicação

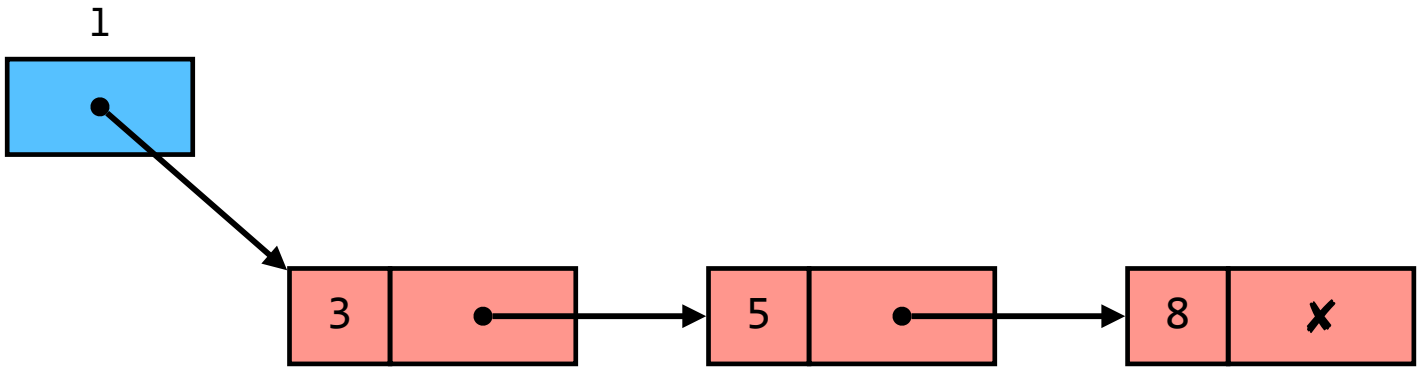
```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  lint m = clone(l);
  return 0;
}
```



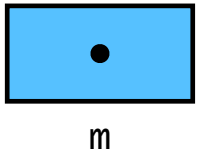
Duplicação

```
lint clone(lint l) {
  lint head = NULL, last = NULL;
  while (l != NULL) {
    if (head == NULL) {
      head = cons(l->valor, NULL);
      last = head;
    } else {
      last->prox = cons(l->valor, NULL);
      last = last->prox;
    }
    l = l->prox;
  }
  return head;
}
```

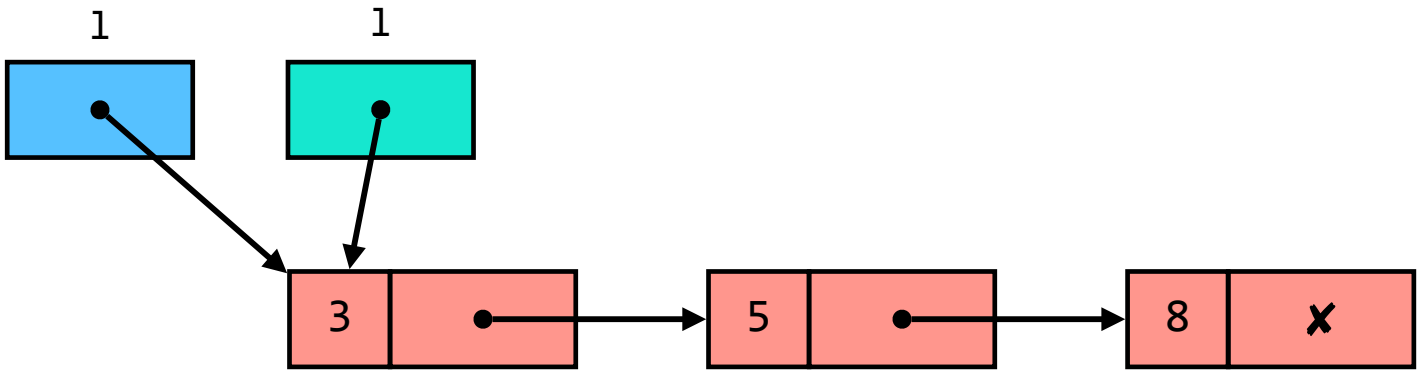
Duplicação



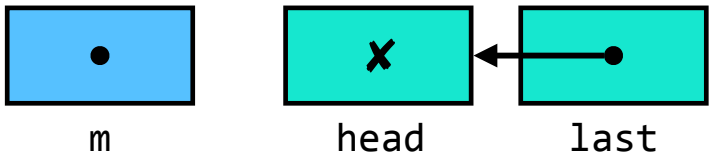

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  lint m = clone(l);
  return 0;
}
```



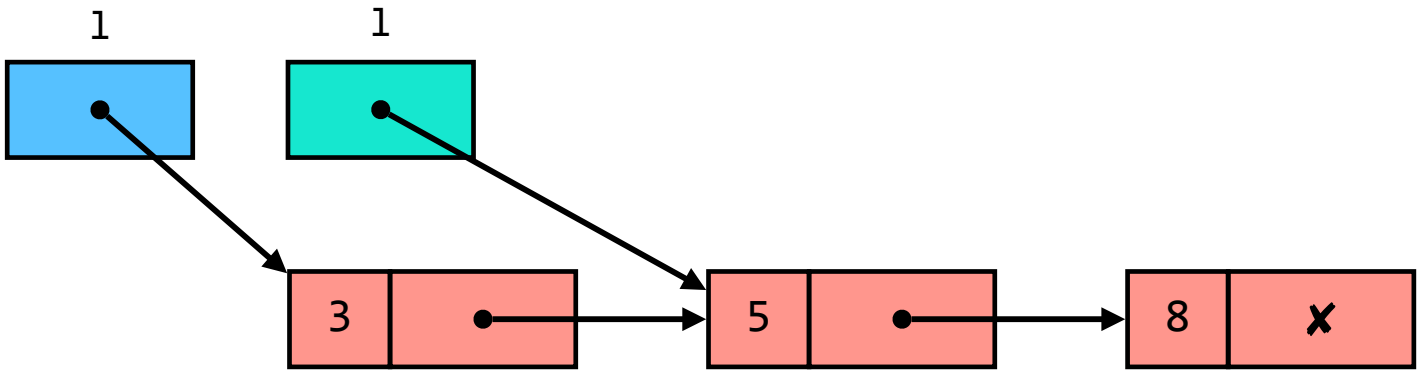
Duplicação



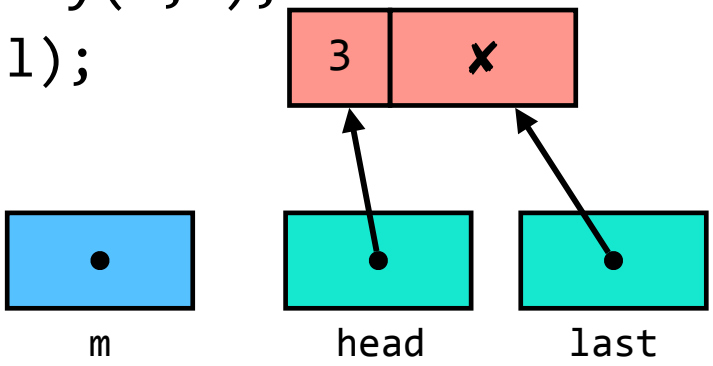

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  lint m = clone(l);
  return 0;
}
```



Duplicação




```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  lint m = clone(l);
  return 0;
}
```



Duplicação

```
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  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  lint m = clone(l);
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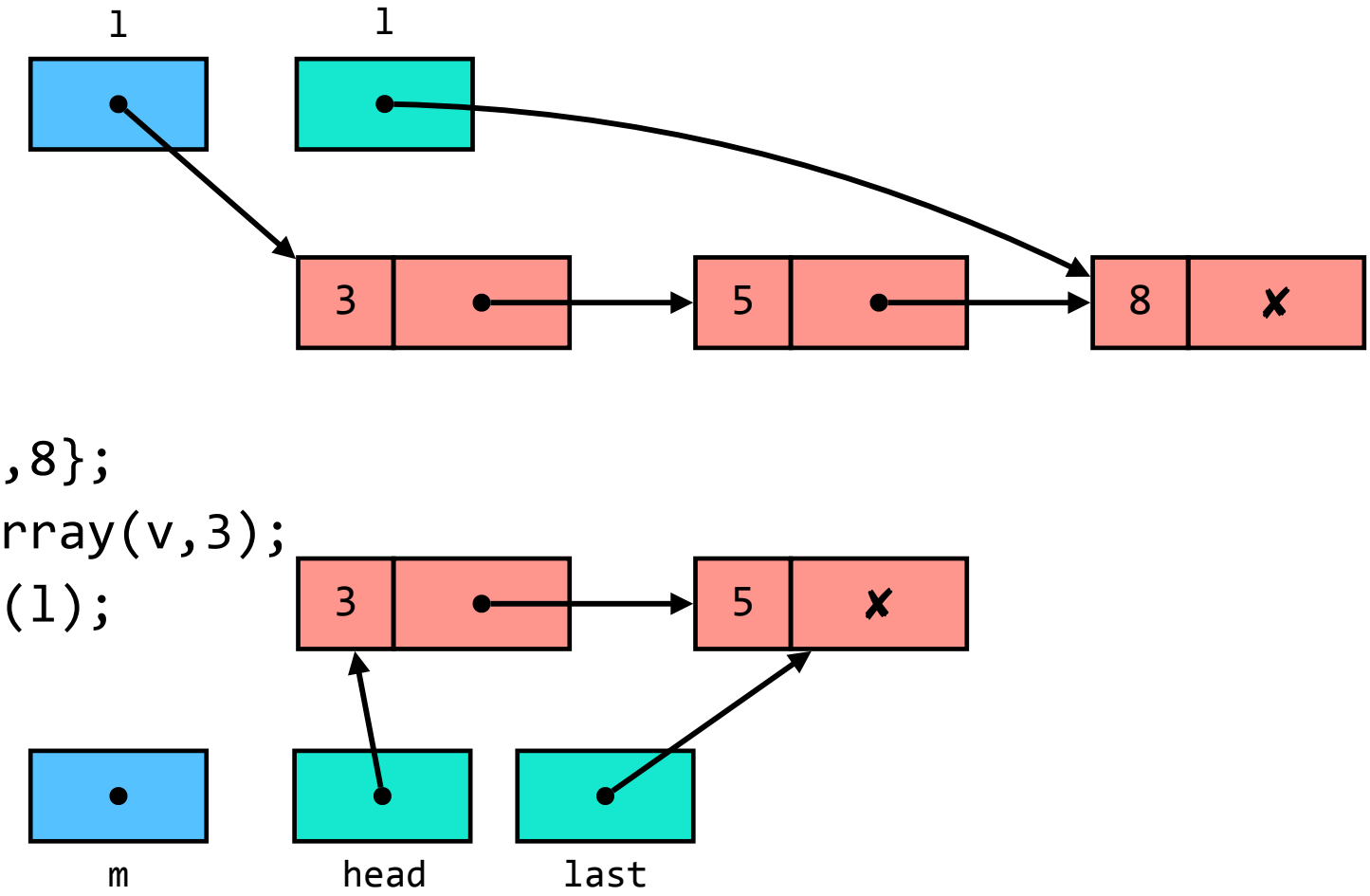
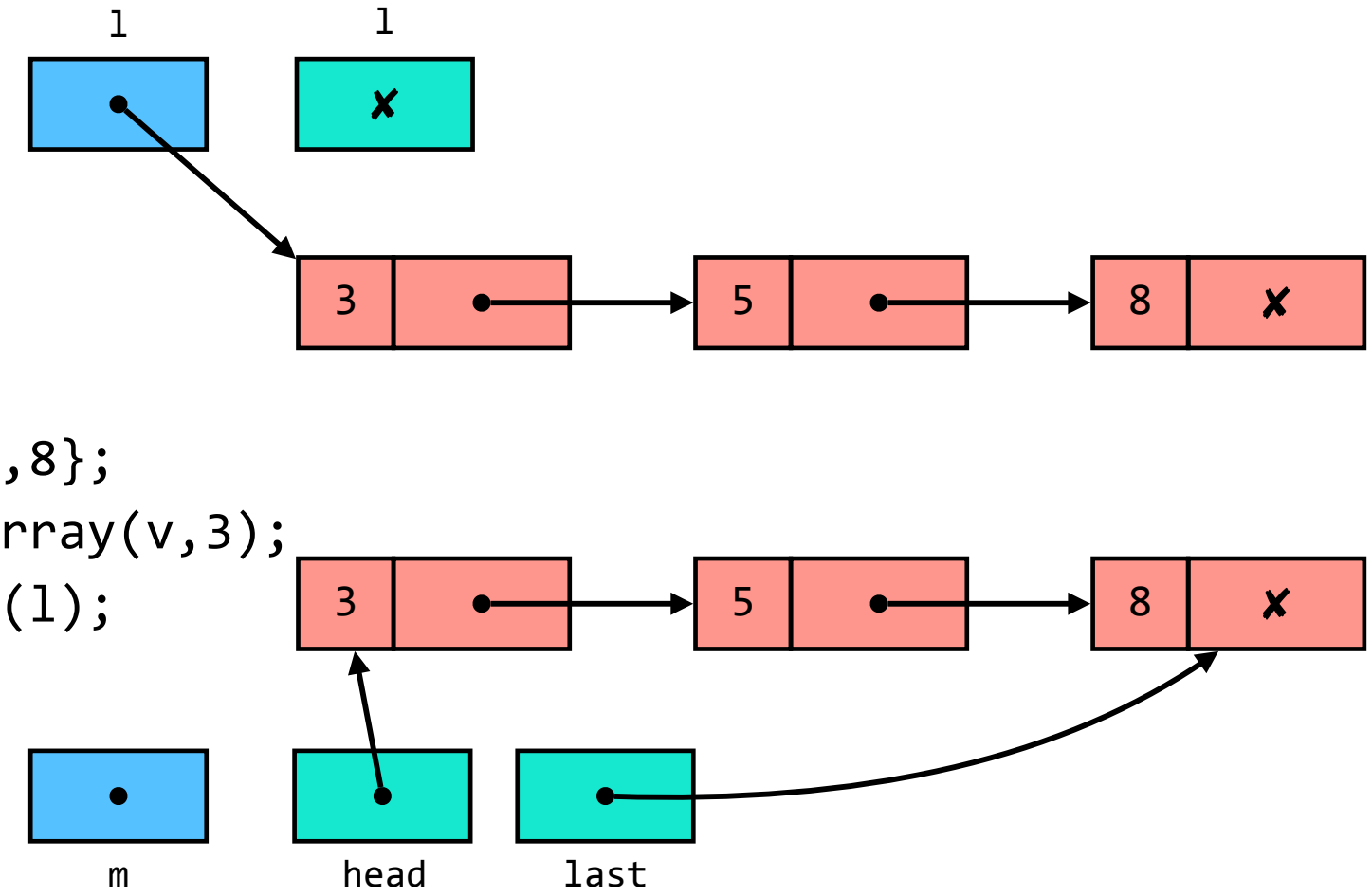
```



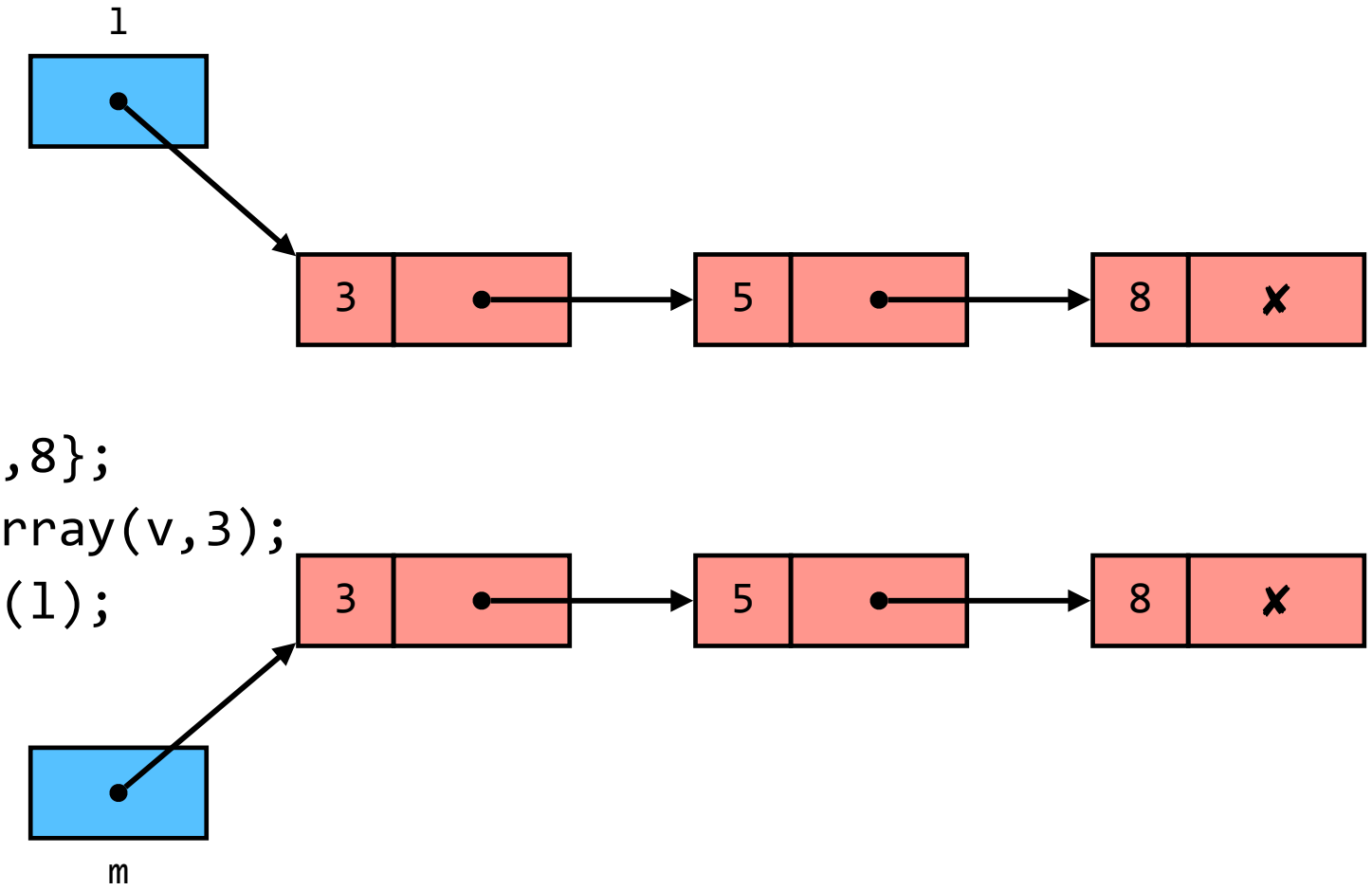
Duplicação

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  lint m = clone(l);
  return 0;
}
```



Duplicação

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  lint m = clone(l);
  return 0;
}
```



Duplicação

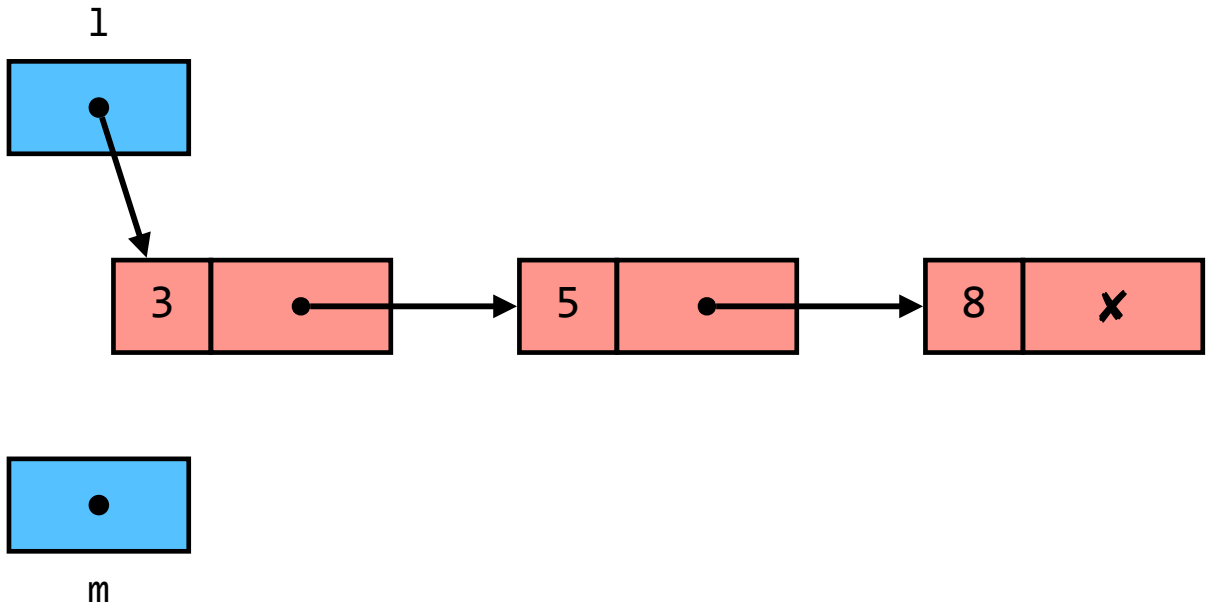
```
lint clone(lint l) {
  lint head = NULL, *last = &head;
  while (l != NULL) {
    *last = cons(l->valor, NULL);
    last = &((*last)->prox);
    l = l->prox;
  }
  return head;
}
```

Aula 17

Pesquisa ordenada

```
lint search(int x, lint l) {
  while (l != NULL && l->valor < x) l = l->prox;
  if (l != NULL && l->valor == x) return l;
  else return NULL;
}

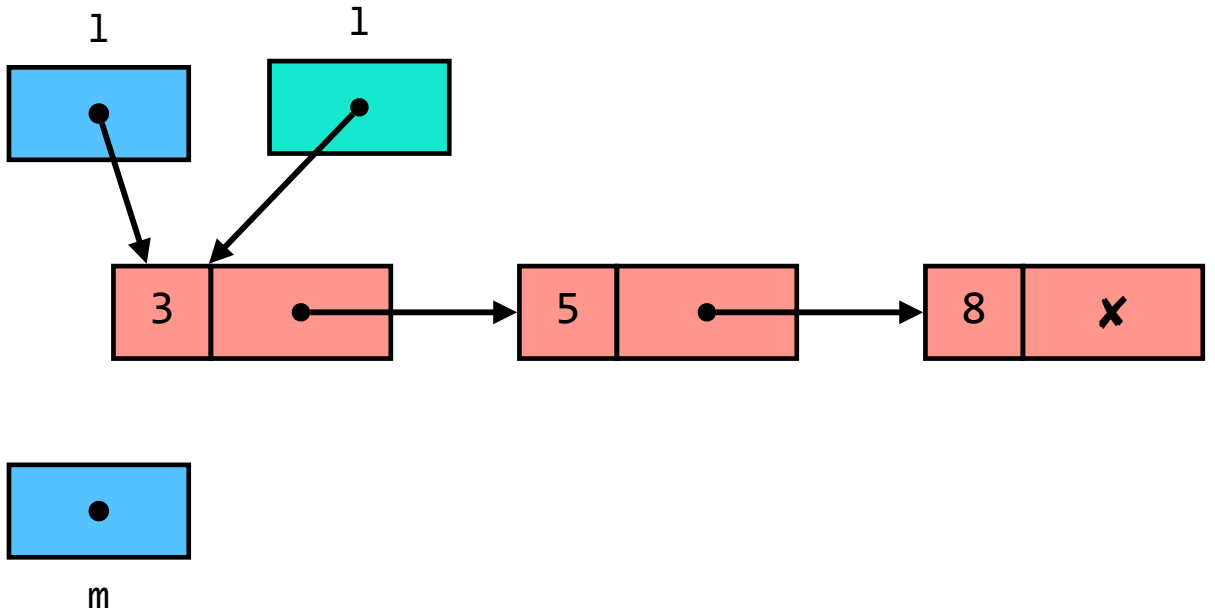
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v, 3);
  lint m = search(5, l);
  return 0;
}
```



Pesquisa ordenada

```
lint search(int x, lint l) {
  while (l != NULL && l->valor < x) l = l->prox;
  if (l != NULL && l->valor == x) return l;
  else return NULL;
}

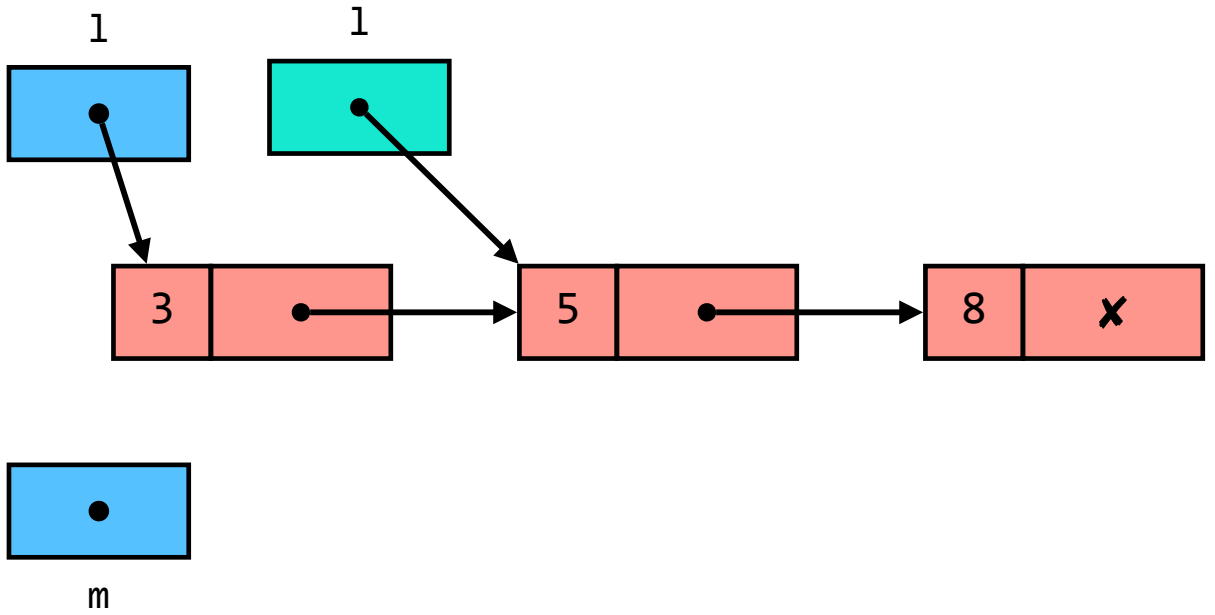
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v, 3);
  lint m = search(5, l);
  return 0;
}
```



Pesquisa ordenada

```
lint search(int x, lint l) {
  while (l != NULL && l->valor < x) l = l->prox;
  if (l != NULL && l->valor == x) return l;
  else return NULL;
}

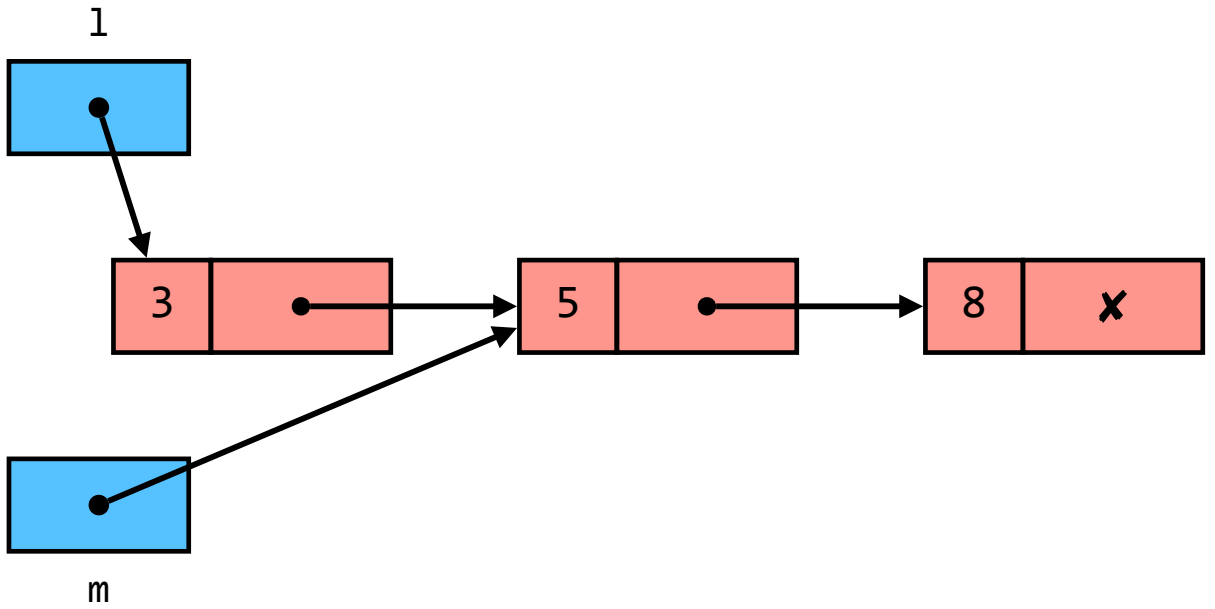
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v, 3);
  lint m = search(5, l);
  return 0;
}
```



Pesquisa ordenada

```
lint search(int x, lint l) {
  while (l != NULL && l->valor < x) l = l->prox;
  if (l != NULL && l->valor == x) return l;
  else return NULL;
}

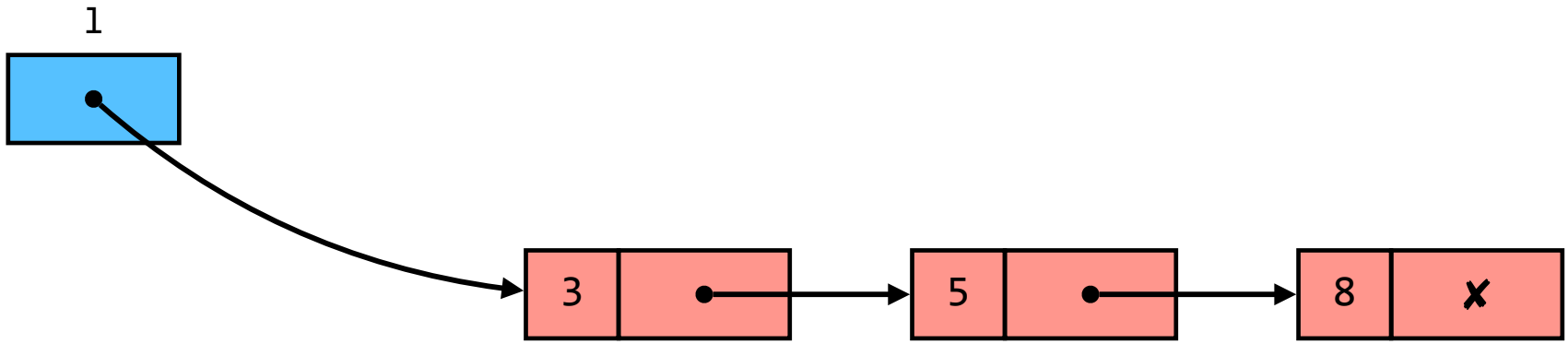
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v, 3);
  lint m = search(5, l);
  return 0;
}
```



Inserção ordenada

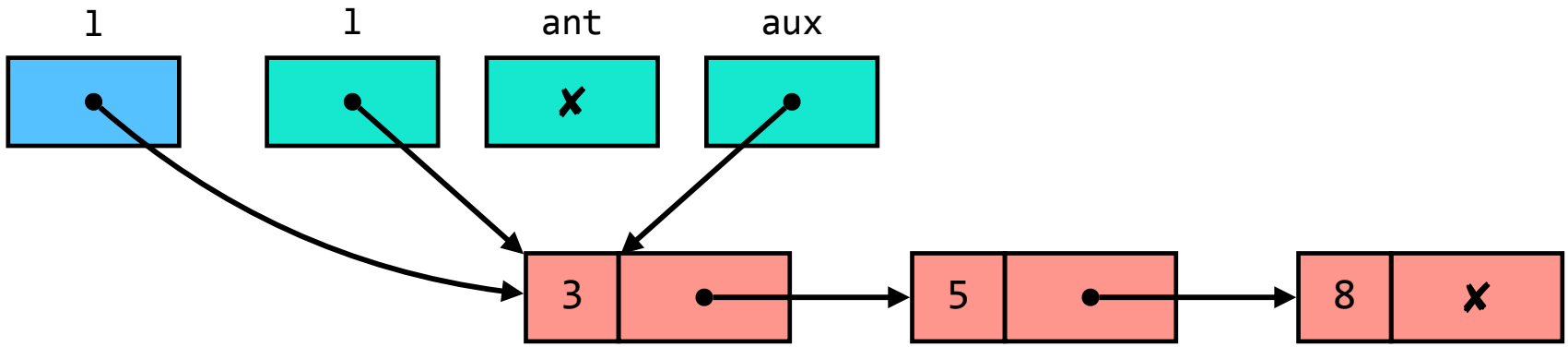
```
lint insert(int x, lint l) {
  …
}
```

Inserção ordenada



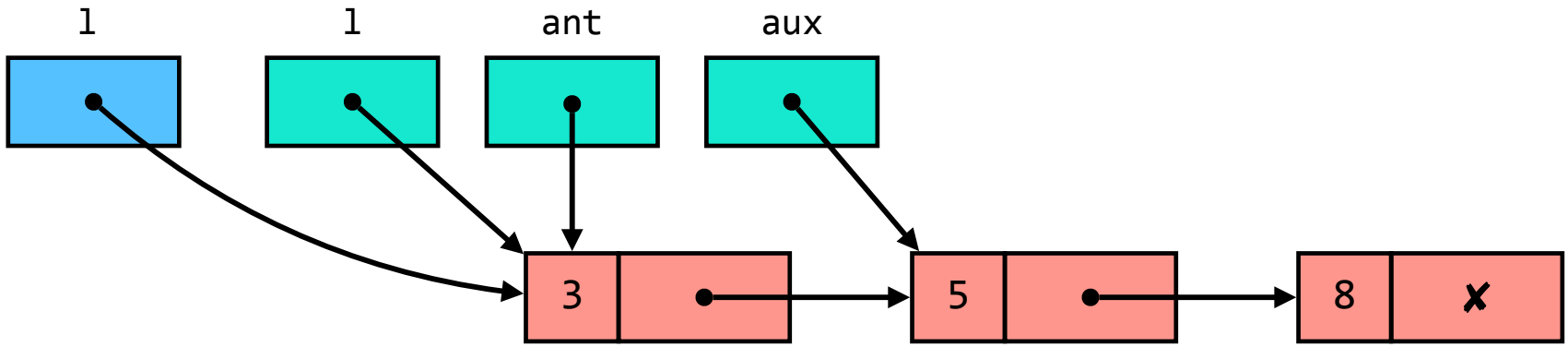

```
int main() {
   int v[] = {3,5,8};
   lint l = fromArray(v,3);
   l = insert(6,l);
   return 0;
}
```

Inserção ordenada



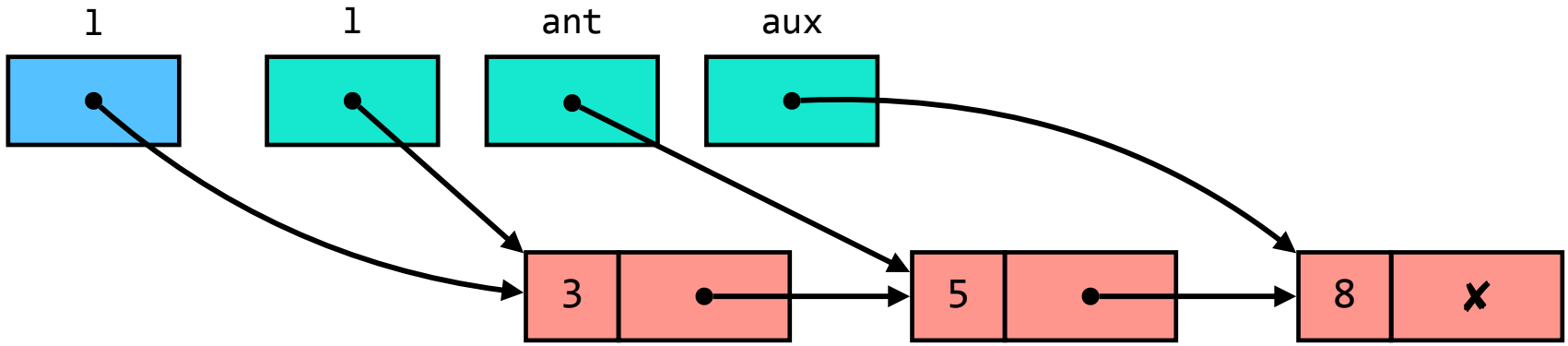

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = insert(6,l);
  return 0;
}
```

Inserção ordenada



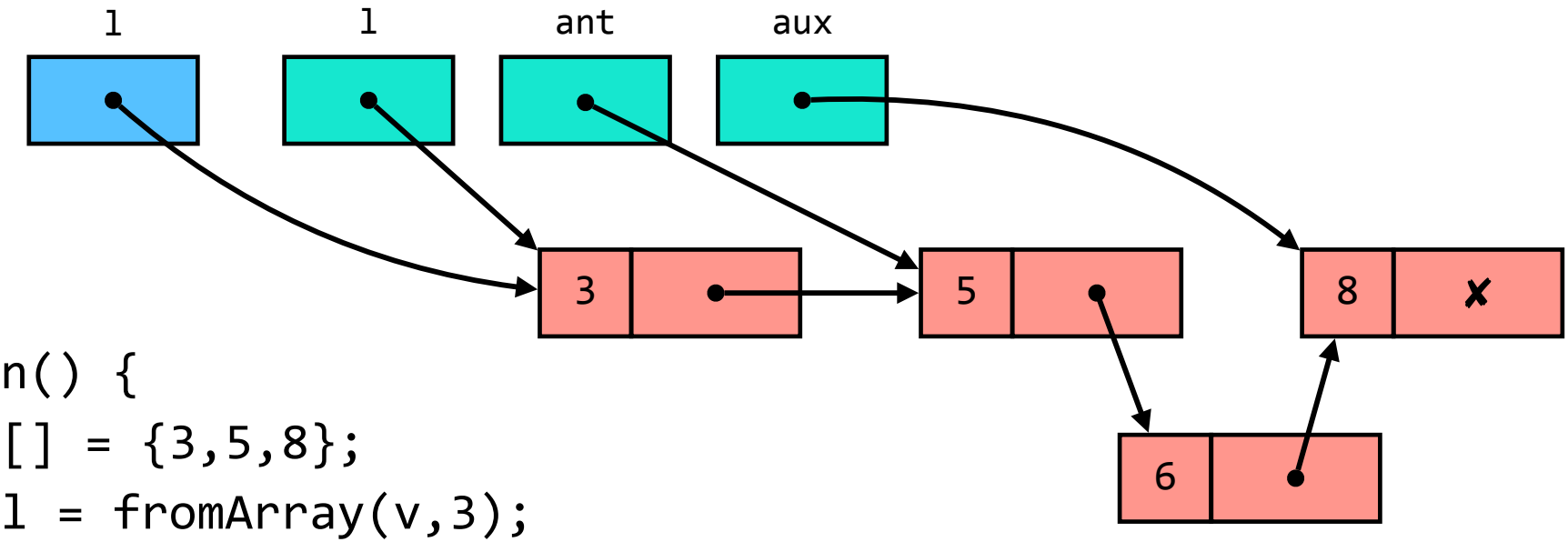

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = insert(6,l);
  return 0;
}
```

Inserção ordenada



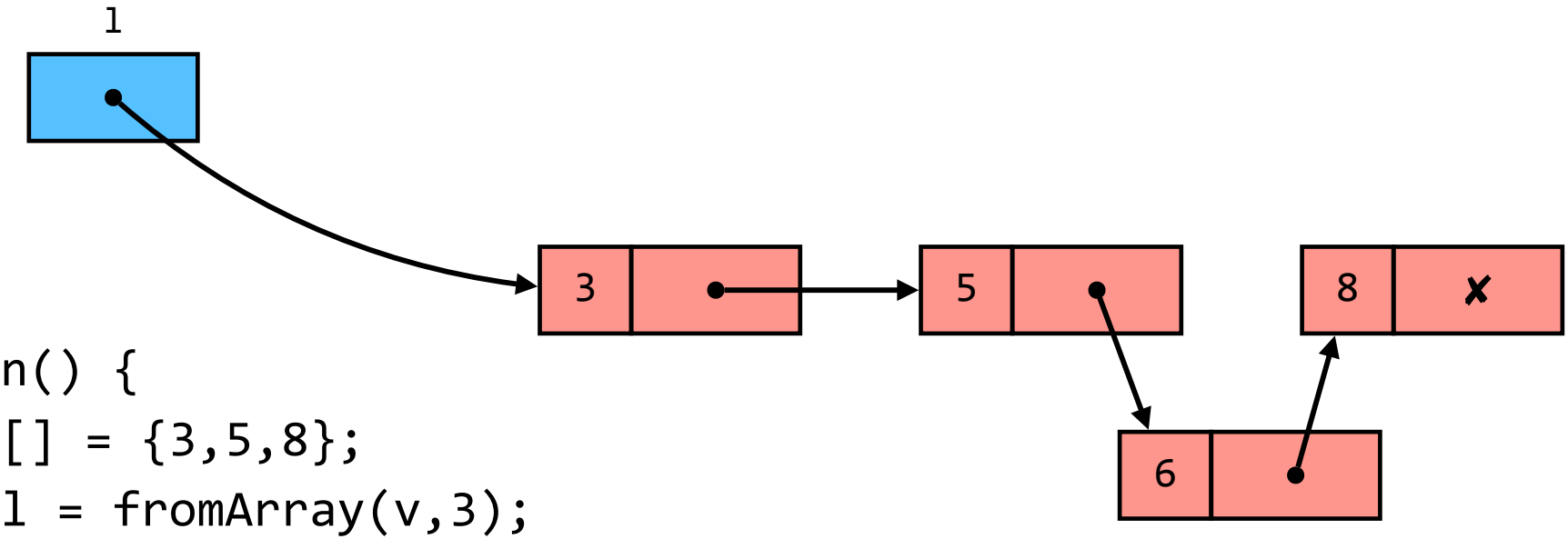

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = insert(6,l);
  return 0;
}
```

Inserção ordenada



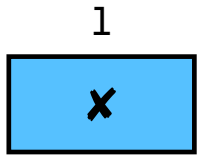

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = insert(6,l);
  return 0;
}
```

Inserção ordenada



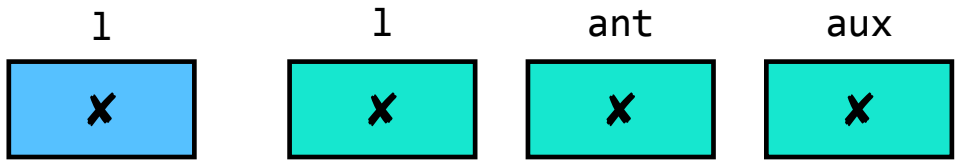

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = insert(6,l);
  return 0;
}
```

Inserção ordenada



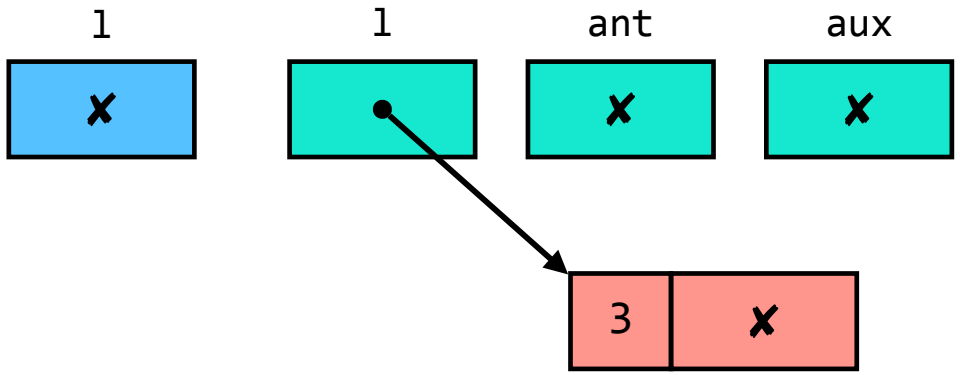

```
int main() {
  lint l = NULL;
  l = insert(3,l);
  return 0;
}
```

Inserção ordenada



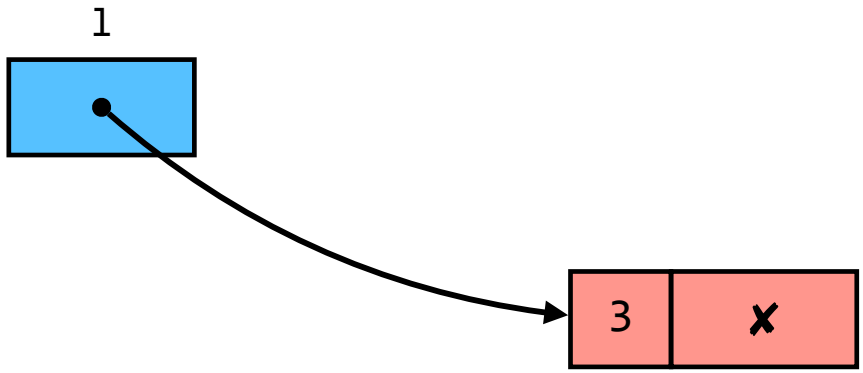

```
int main() {
  lint l = NULL;
  l = insert(3,l);
  return 0;
}
```

Inserção ordenada




```
int main() {
  lint l = NULL;
  l = insert(3,l);
  return 0;
}
```

Inserção ordenada

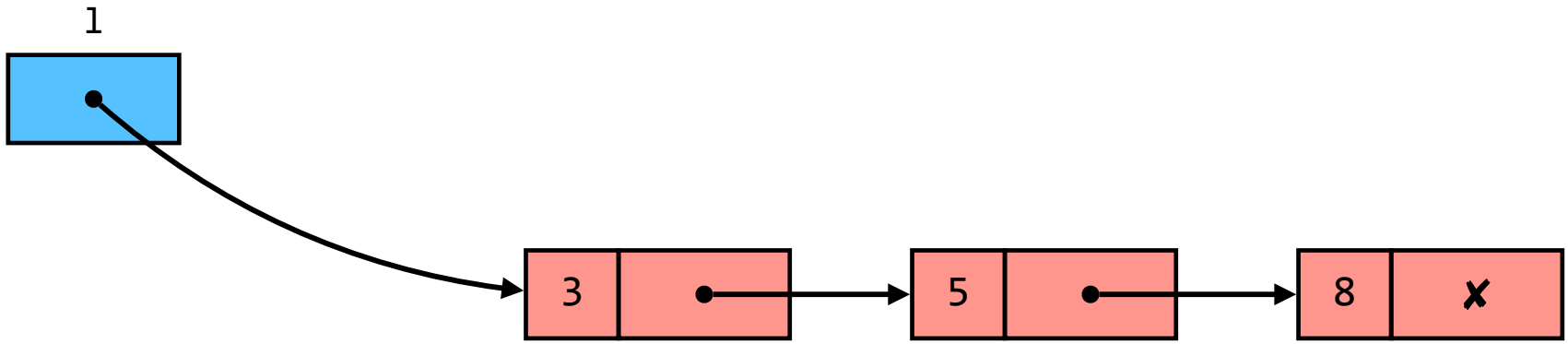



```
int main() {
  lint l = NULL;
  l = insert(3,l);
  return 0;
}
```

Inserção ordenada

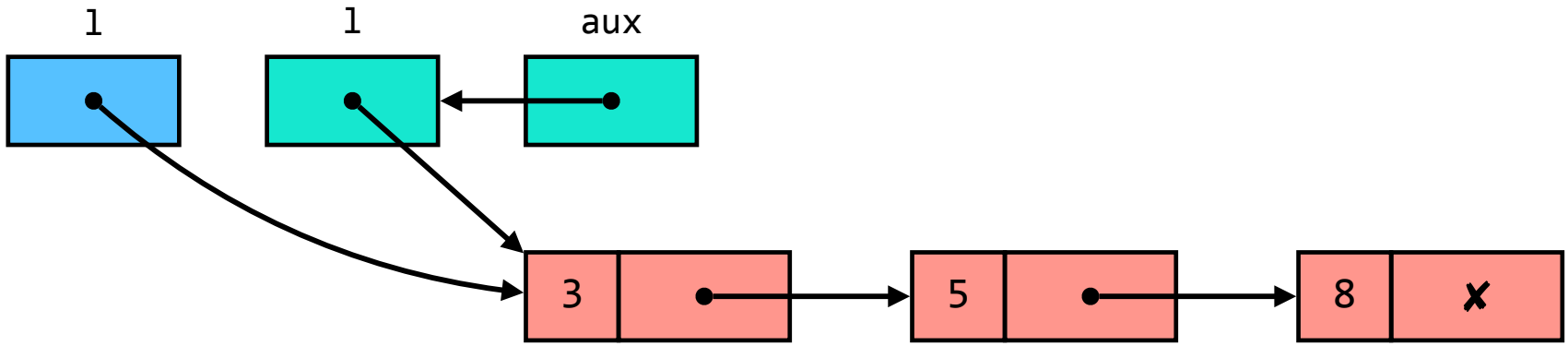
```
lint insert(int x, lint l) {
  lint ant = NULL, aux = l;
  while (aux != NULL && aux->valor < x) {
    ant = aux;
    aux = aux->prox;
  }
  if (ant == NULL) l = cons(x, l);
  else ant->prox = cons(x, aux);
  return l;
}
```

Inserção ordenada



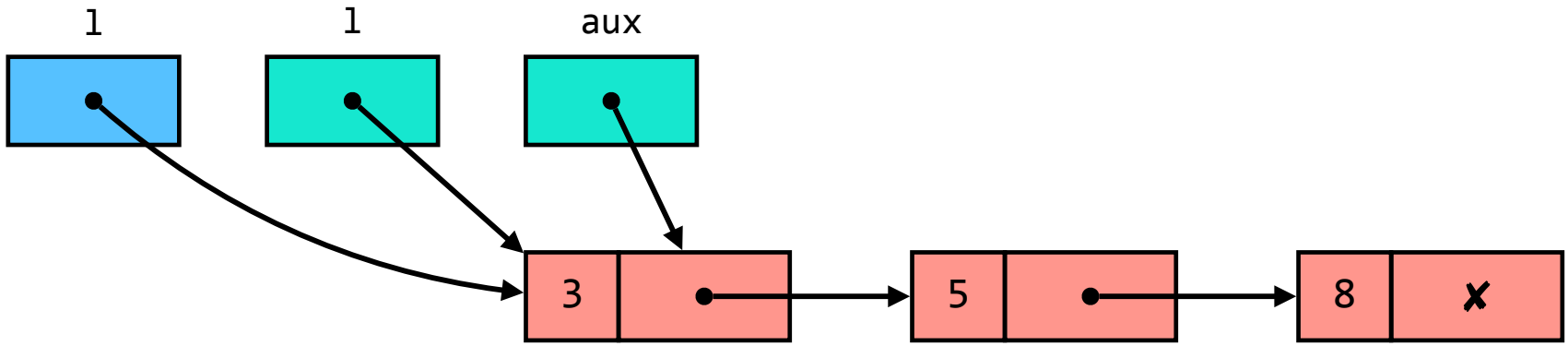

```
int main() {
   int v[] = {3,5,8};
   lint l = fromArray(v,3);
   l = insert(6,l);
   return 0;
}
```

Inserção ordenada



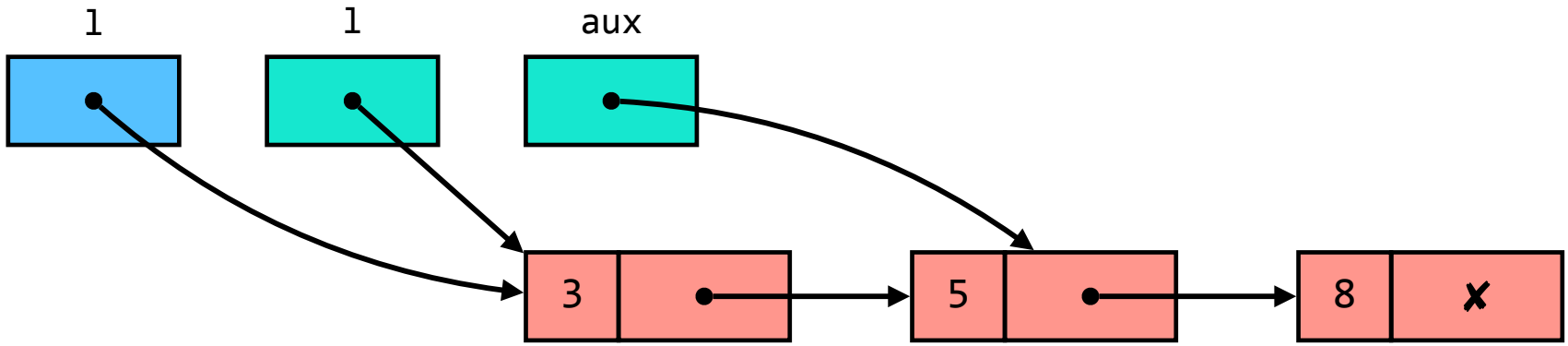

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = insert(6,l);
  return 0;
}
```

Inserção ordenada



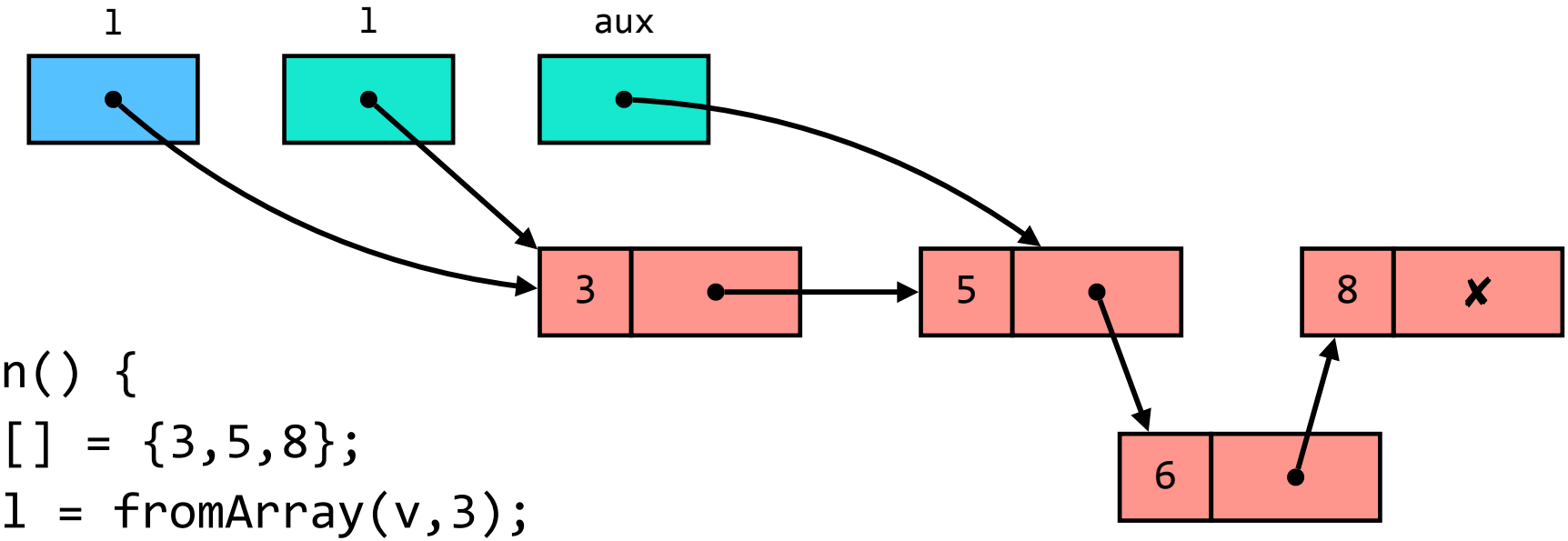

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = insert(6,l);
  return 0;
}
```

Inserção ordenada



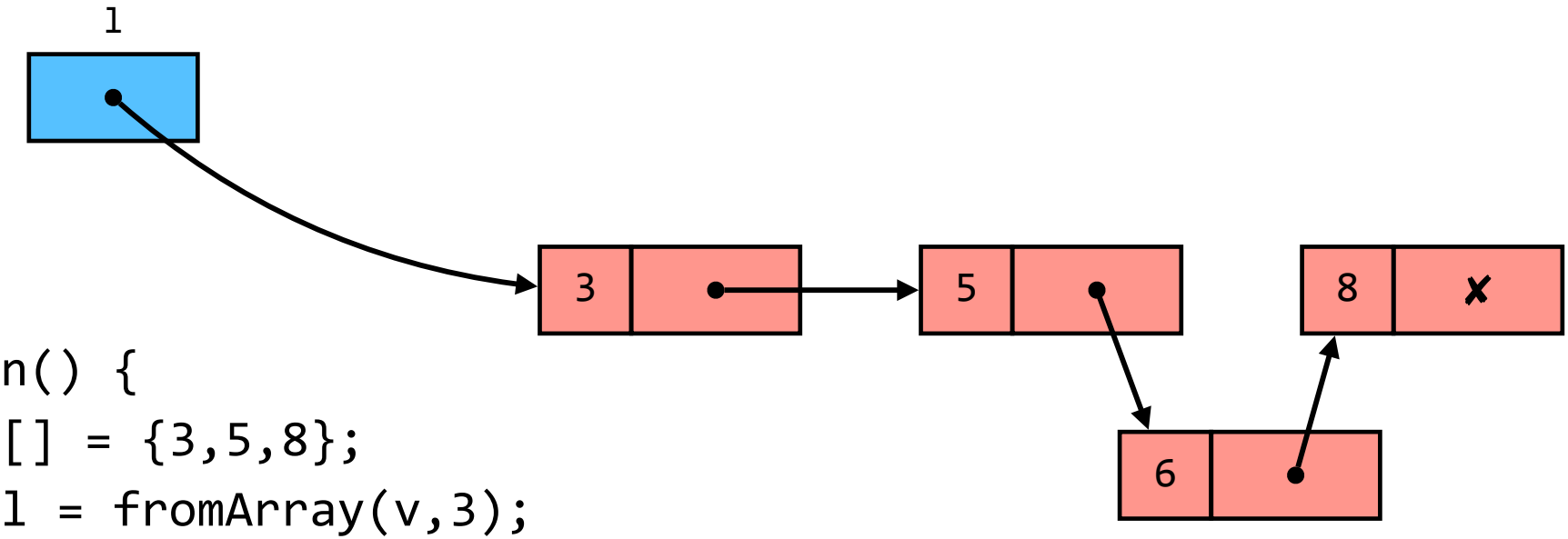

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = insert(6,l);
  return 0;
}
```

Inserção ordenada




```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = insert(6,l);
  return 0;
}
```

Inserção ordenada




```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = insert(6,l);
  return 0;
}
```

Inserção ordenada

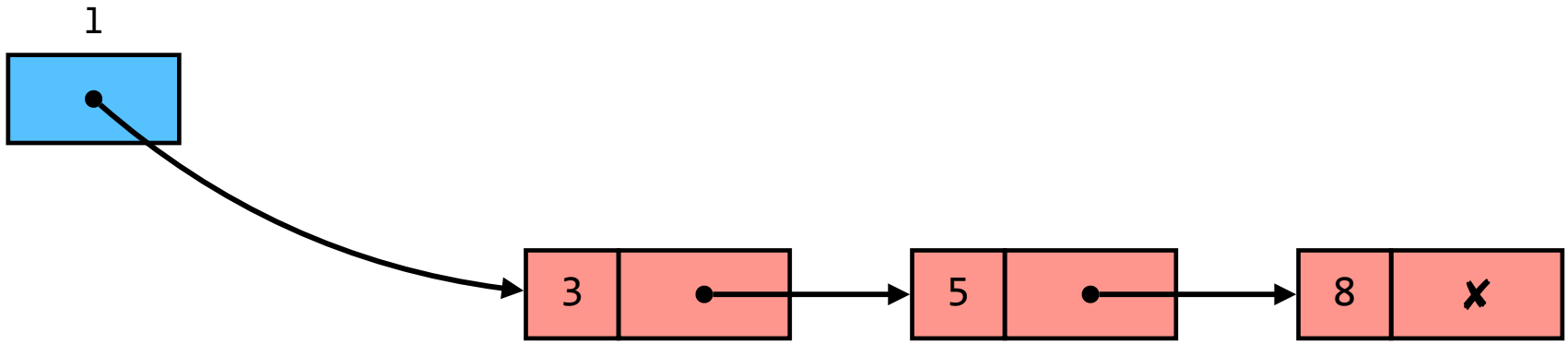
```
lint insert(int x, lint l) {
  lint *aux = &l;
  while ((*aux) != NULL && (*aux)->valor < x) {
    aux = &((*aux)->prox);
  }
  *aux = cons(x,*aux);
  return l;
}
```

Aula 18

Remoção ordenada

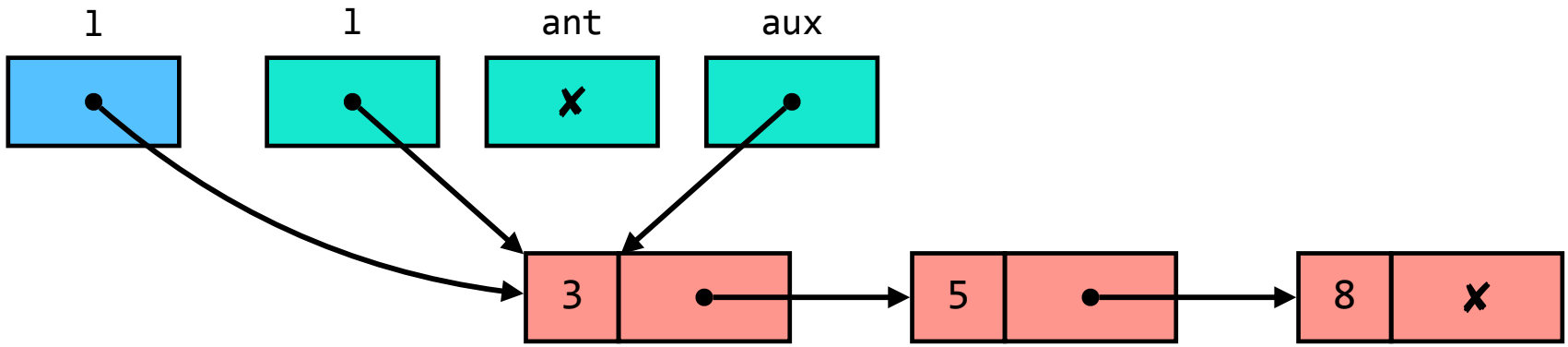
```
lint delete(int x, lint l) {
  …
}
```

Remoção ordenada



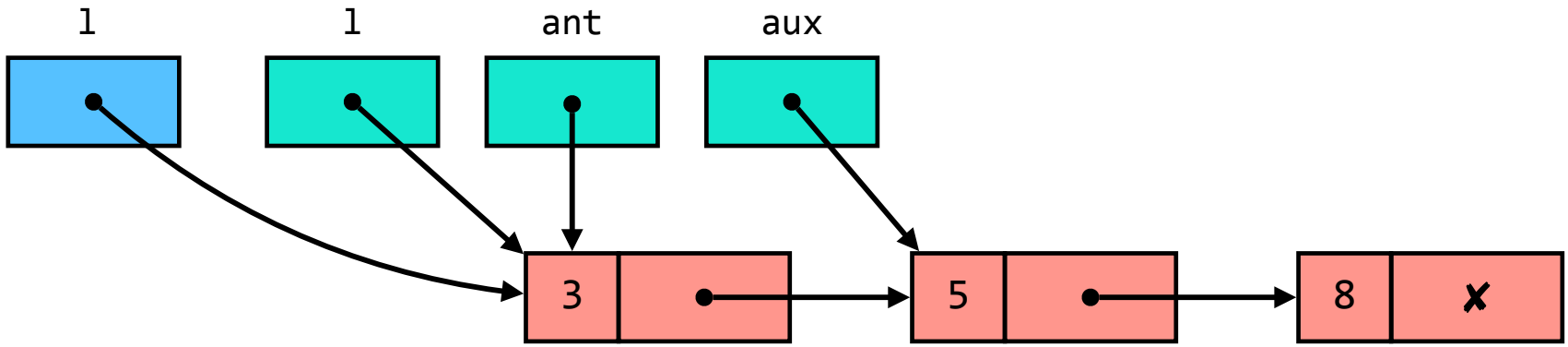

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = delete(5,l);
  return 0;
}
```

Remoção ordenada



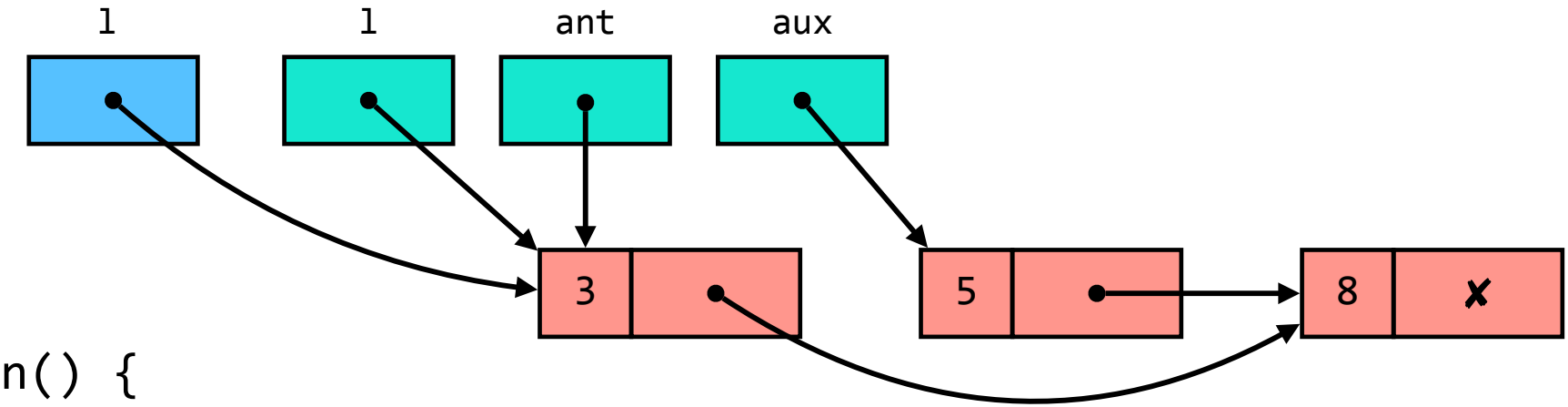

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = delete(5,l);
  return 0;
}
```

Remoção ordenada



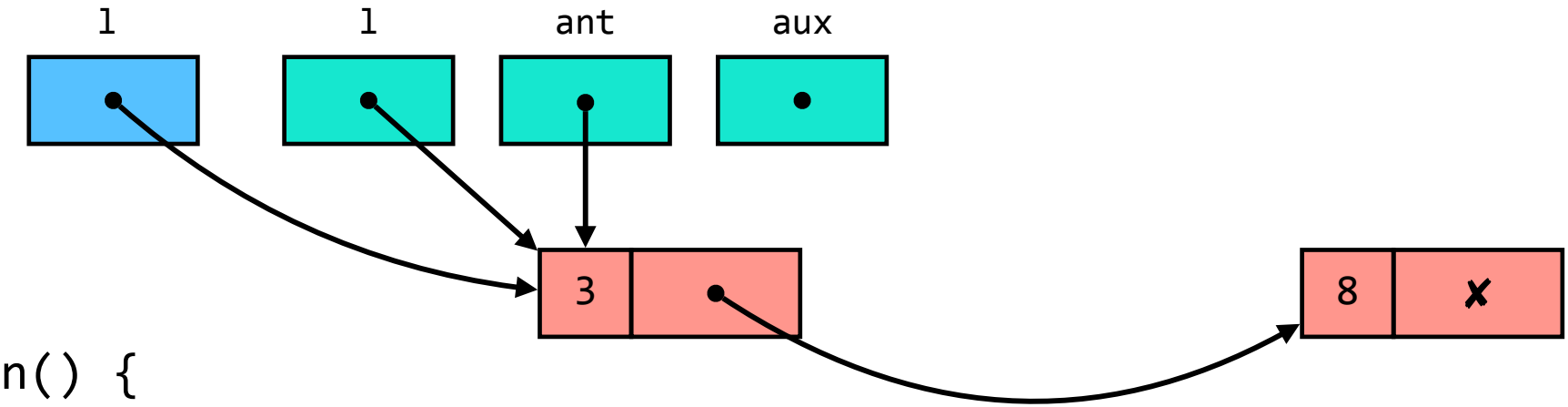

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = delete(5,l);
  return 0;
}
```

Remoção ordenada



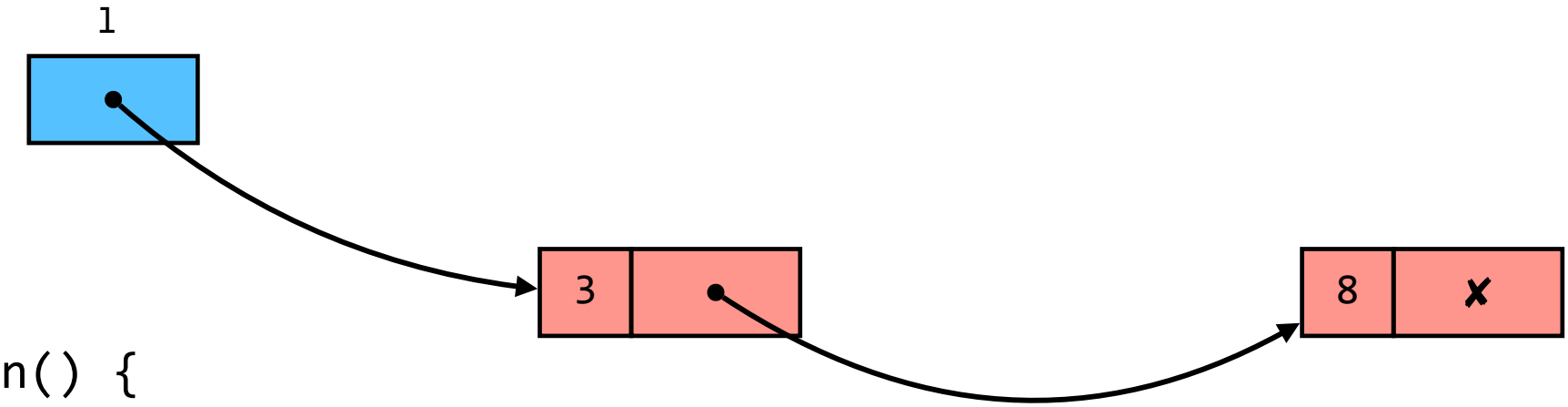

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = delete(5,l);
  return 0;
}
```

Remoção ordenada




```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = delete(5,l);
  return 0;
}
```

Remoção ordenada

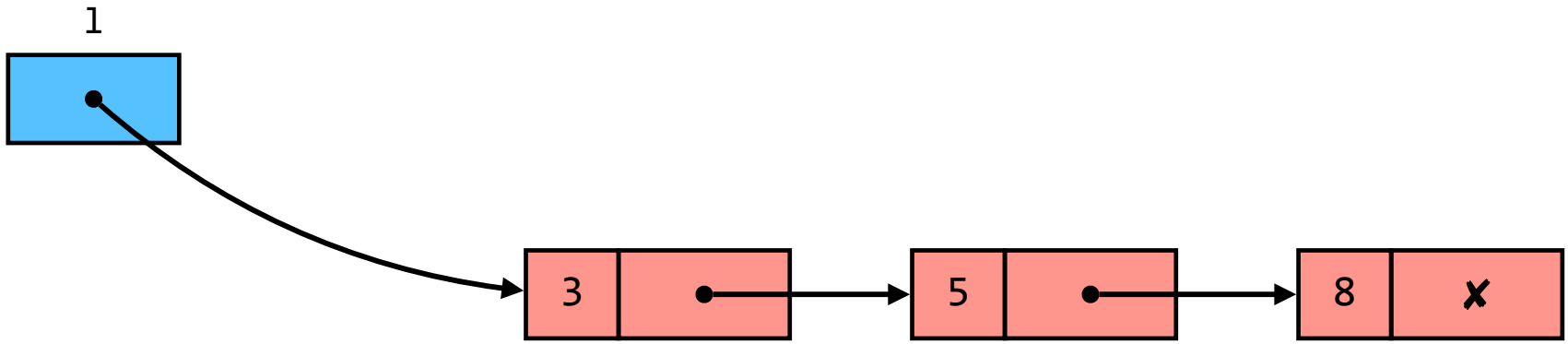



```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = delete(5,l);
  return 0;
}
```

Remoção ordenada

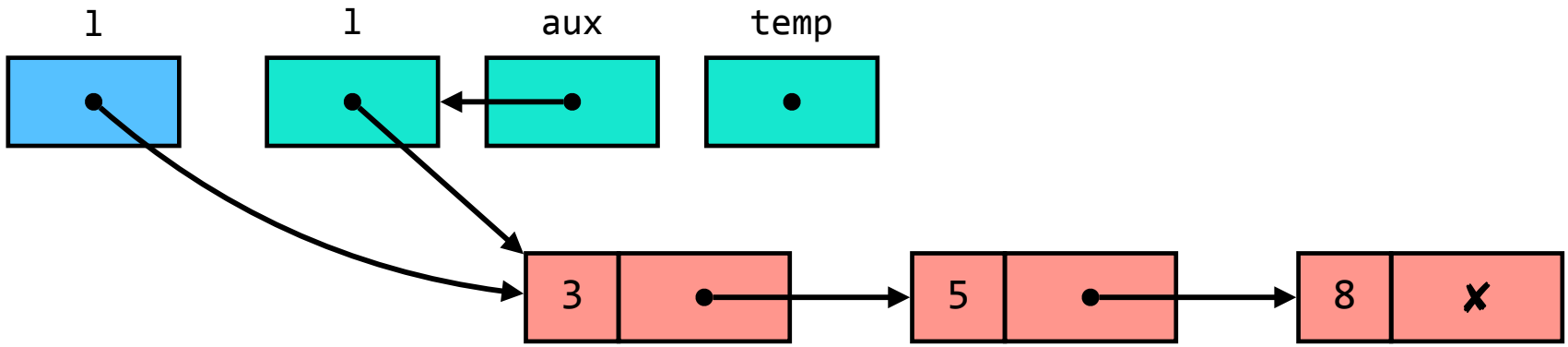
```
lint delete(int x, lint l) {
  lint ant = NULL, aux = l;
  while (aux != NULL && aux->valor < x) {
    ant = aux;
    aux = aux->prox;
  }
  if (aux == NULL || aux->valor != x) return l;
  if (ant == NULL) l = aux->prox;
  else ant->prox = aux->prox;
  free(aux);
  return l;
}
```

Remoção ordenada



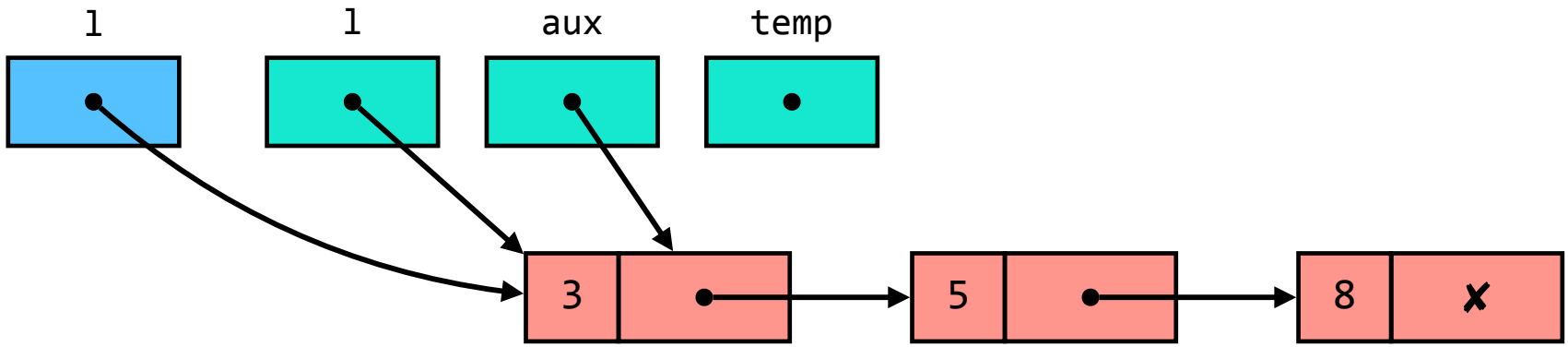

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = delete(5,l);
  return 0;
}
```

Remoção ordenada



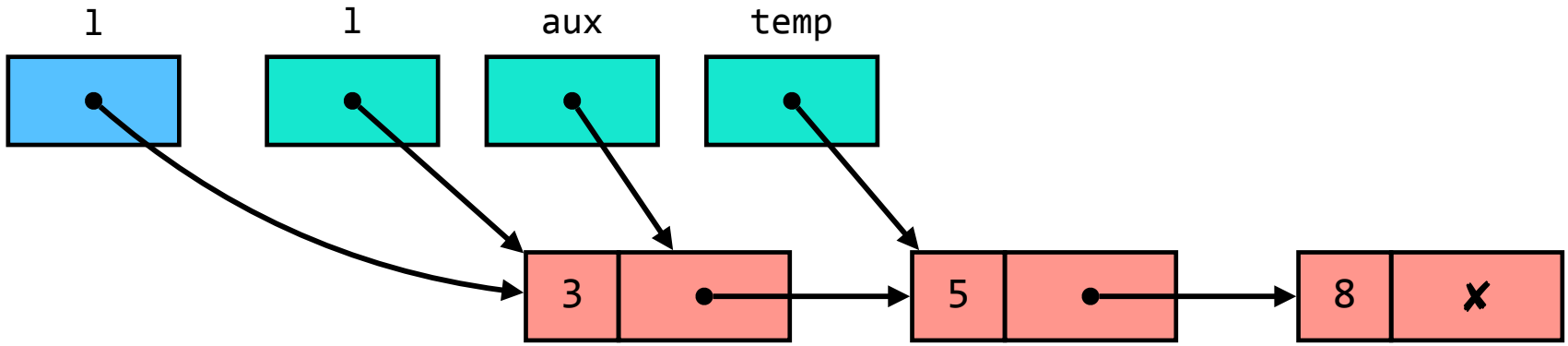

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = delete(5,l);
  return 0;
}
```

Remoção ordenada



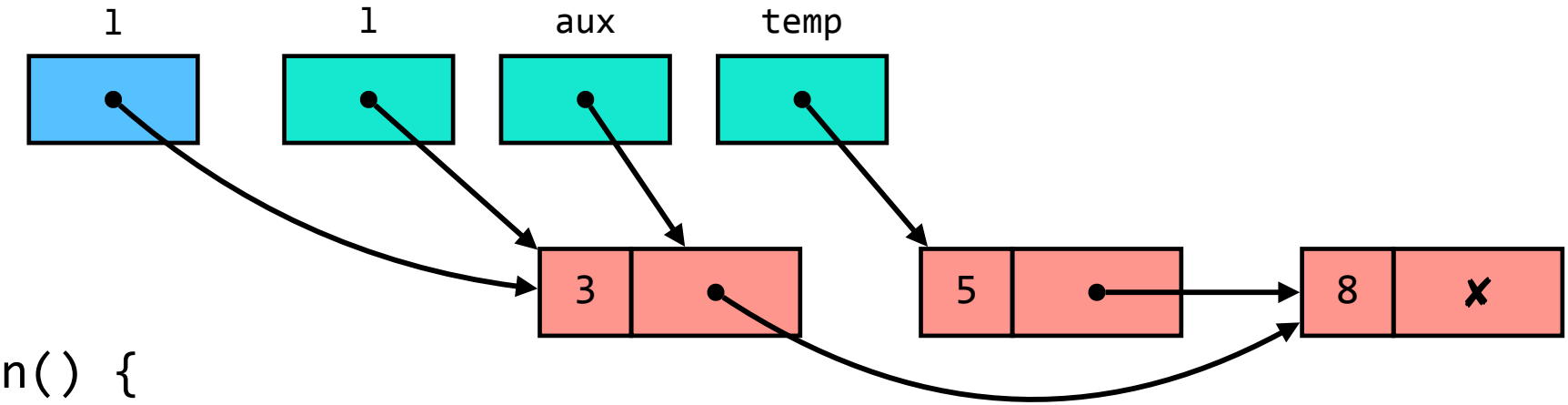

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = delete(5,l);
  return 0;
}
```

Remoção ordenada



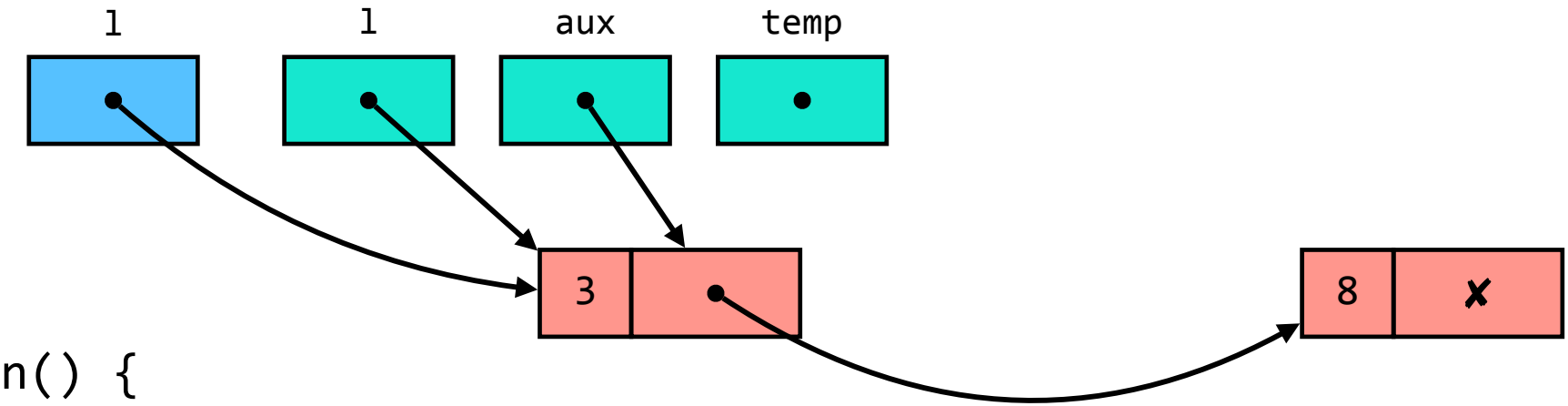

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = delete(5,l);
  return 0;
}
```

Remoção ordenada



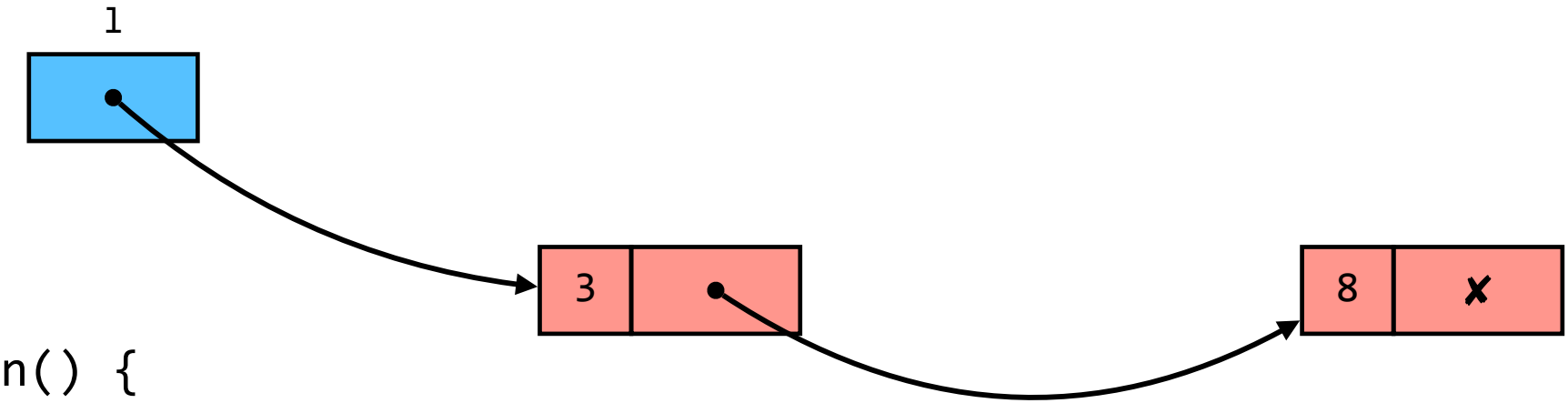

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = delete(5,l);
  return 0;
}
```

Remoção ordenada




```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = delete(5,l);
  return 0;
}
```

Remoção ordenada



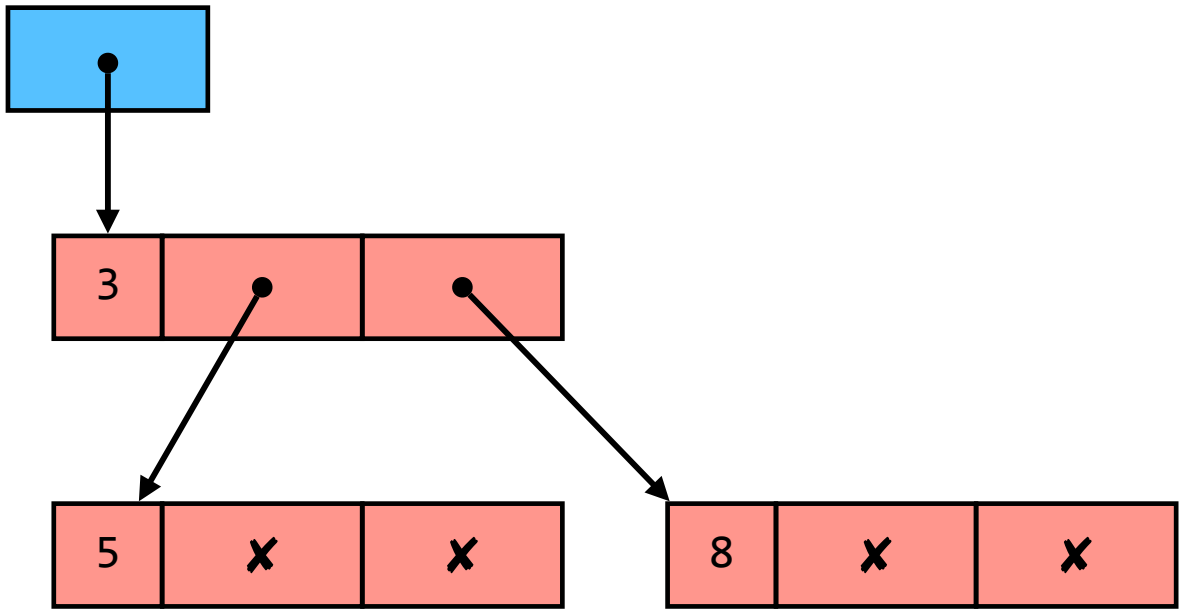

```
int main() {
  int v[] = {3,5,8};
  lint l = fromArray(v,3);
  l = delete(5,l);
  return 0;
}
```

Remoção ordenada

```
lint delete(int x, lint l) {
  lint *aux = &l, temp;
  while ((*aux) != NULL && (*aux)->valor < x) {
    aux = &((*aux)->prox);
  }
  if ((*aux) == NULL || (*aux)->valor != x) return l;
  temp = *aux;
  *aux = (*aux)->prox;
  free(temp);
  return l;
}
```

Aula 19

Árvores binárias




```
typedef struct abin_no {
  int valor;
  struct abin_no *esq, *dir;
} *abin;
```

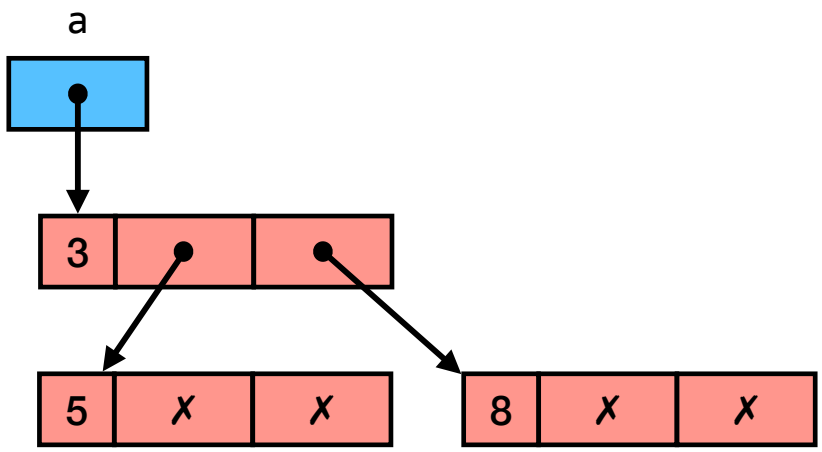
Disclaimer

Inserção na raiz

```
abin mkroot(int x, abin e, abin d) {
  abin new = malloc(sizeof(struct abin_no));
  new->valor = x;
  new->esq = e;
  new->dir = d;
  return new;
}
```

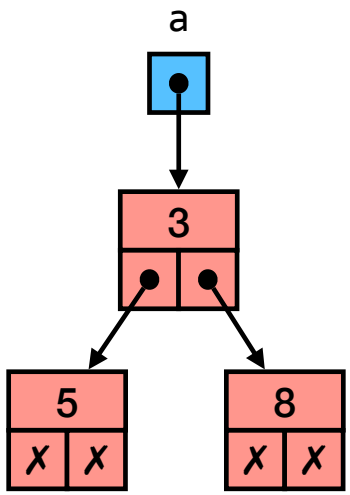
Inserção na raiz

```
int main() {
  abin a = mkroot(3, mkroot(5, NULL, NULL), mkroot(8, NULL, NULL));
  return 0;
}
```



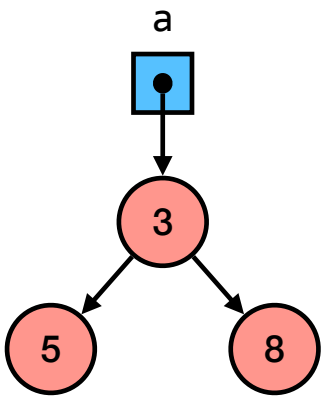
Inserção na raiz

```
int main() {
  abin a = mkroot(3, mkroot(5, NULL, NULL), mkroot(8, NULL, NULL));
  return 0;
}
```



Inserção na raiz

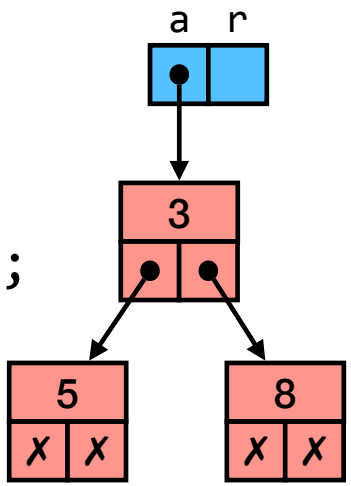
```
int main() {
  abin a = mkroot(3, mkroot(5, NULL, NULL), mkroot(8, NULL, NULL));
  return 0;
}
```



Tamanho

```
int size(abin a) {
  int r;
  if (a == NULL) r = 0;
  else r = 1 + size(a->esq) + size(a->dir);
  return r;
}

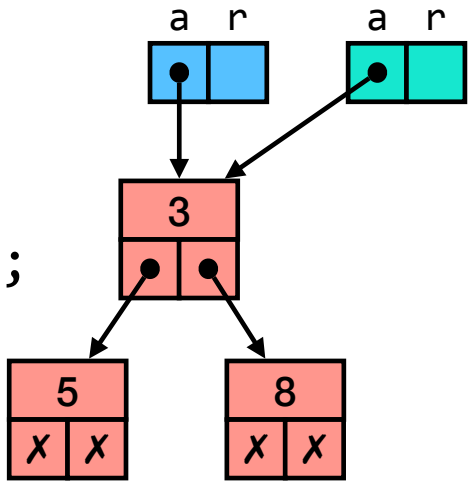
int main() {
  abin a = mkroot(3, mkroot(5, NULL, NULL), mkroot(8, NULL, NULL));
  int r = size(a);
  return 0;
}
```



Tamanho

```
int size(abin a) {
  int r;
  if (a == NULL) r = 0;
  else r = 1 + size(a->esq) + size(a->dir);
  return r;
}

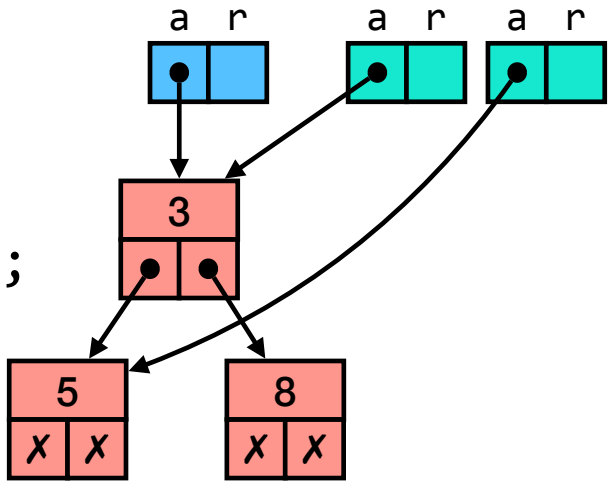
int main() {
  abin a = mkroot(3, mkroot(5, NULL, NULL), mkroot(8, NULL, NULL));
  int r = size(a);
  return 0;
}
```



Tamanho

```
int size(abin a) {
  int r;
  if (a == NULL) r = 0;
  else r = 1 + size(a->esq) + size(a->dir);
  return r;
}

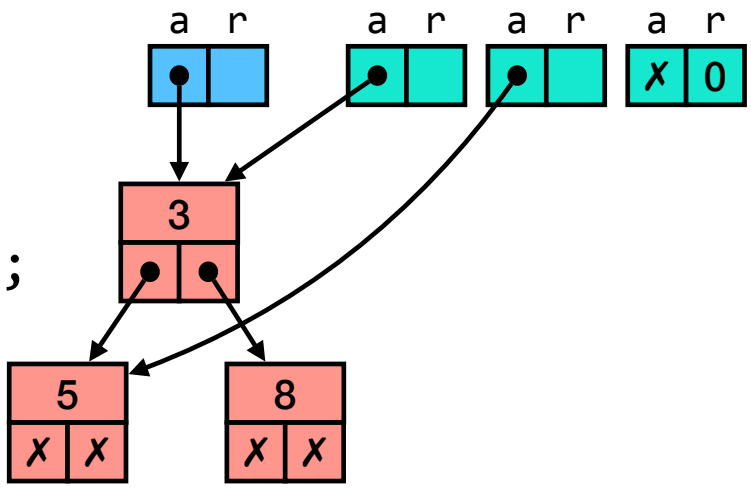
int main() {
  abin a = mkroot(3, mkroot(5, NULL, NULL), mkroot(8, NULL, NULL));
  int r = size(a);
  return 0;
}
```



Tamanho

```
int size(abin a) {
  int r;
  if (a == NULL) r = 0;
  else r = 1 + size(a->esq) + size(a->dir);
  return r;
}

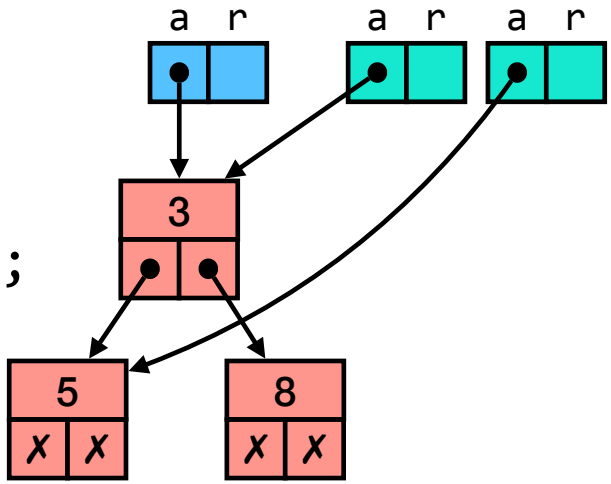
int main() {
  abin a = mkroot(3, mkroot(5, NULL, NULL), mkroot(8, NULL, NULL));
  int r = size(a);
  return 0;
}
```



Tamanho

```
int size(abin a) {
  int r;
  if (a == NULL) r = 0;
  else r = 1 + size(a->esq) + size(a->dir);
  return r;
}

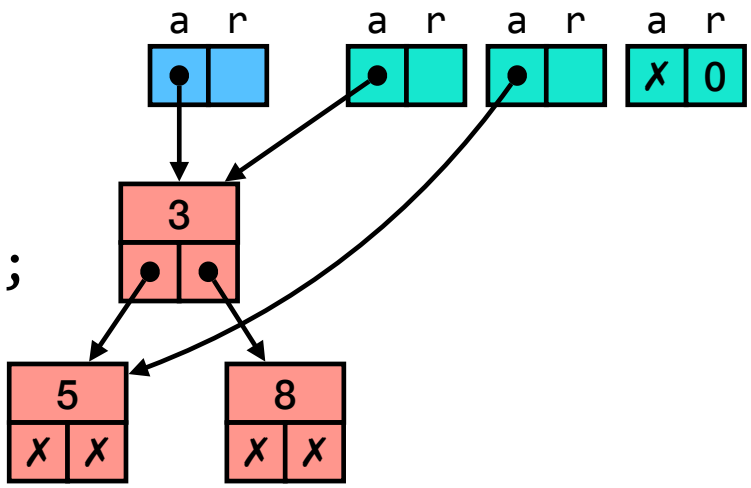
int main() {
  abin a = mkroot(3, mkroot(5, NULL, NULL), mkroot(8, NULL, NULL));
  int r = size(a);
  return 0;
}
```



Tamanho

```
int size(abin a) {
  int r;
  if (a == NULL) r = 0;
  else r = 1 + size(a->esq) + size(a->dir);
  return r;
}

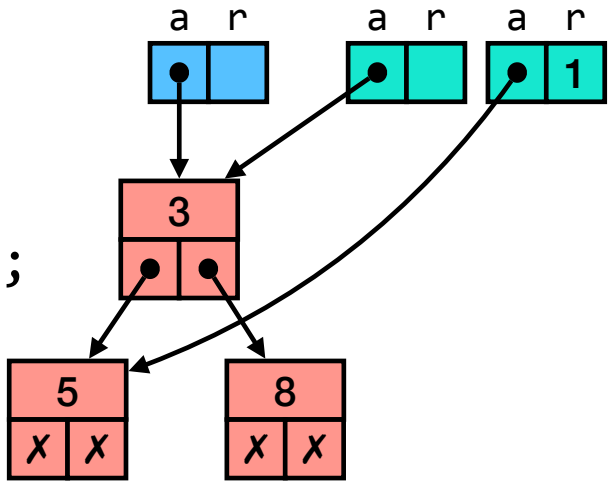
int main() {
  abin a = mkroot(3, mkroot(5, NULL, NULL), mkroot(8, NULL, NULL));
  int r = size(a);
  return 0;
}
```



Tamanho

```
int size(abin a) {
  int r;
  if (a == NULL) r = 0;
  else r = 1 + size(a->esq) + size(a->dir);
  return r;
}

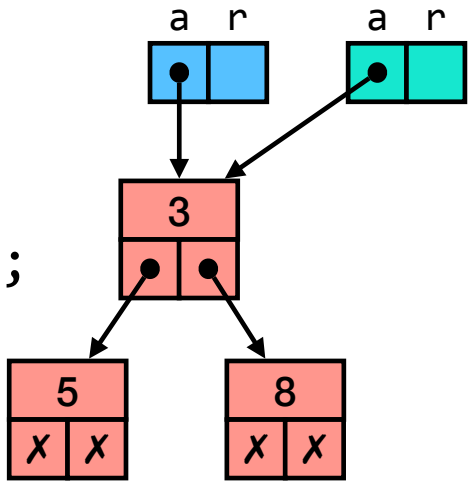
int main() {
  abin a = mkroot(3, mkroot(5, NULL, NULL), mkroot(8, NULL, NULL));
  int r = size(a);
  return 0;
}
```



Tamanho

```
int size(abin a) {
  int r;
  if (a == NULL) r = 0;
  else r = 1 + size(a->esq) + size(a->dir);
  return r;
}

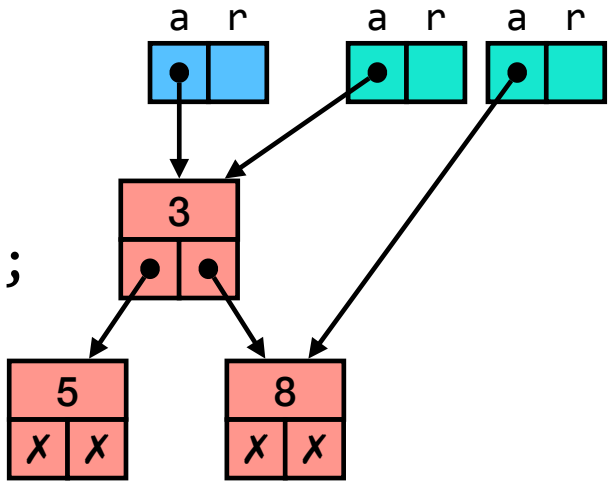
int main() {
  abin a = mkroot(3, mkroot(5, NULL, NULL), mkroot(8, NULL, NULL));
  int r = size(a);
  return 0;
}
```



Tamanho

```
int size(abin a) {
  int r;
  if (a == NULL) r = 0;
  else r = 1 + size(a->esq) + size(a->dir);
  return r;
}

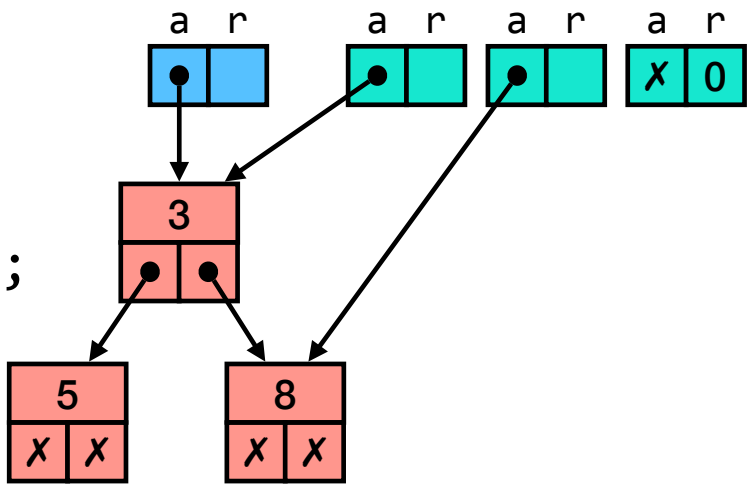
int main() {
  abin a = mkroot(3, mkroot(5, NULL, NULL), mkroot(8, NULL, NULL));
  int r = size(a);
  return 0;
}
```



Tamanho

```
int size(abin a) {
  int r;
  if (a == NULL) r = 0;
  else r = 1 + size(a->esq) + size(a->dir);
  return r;
}

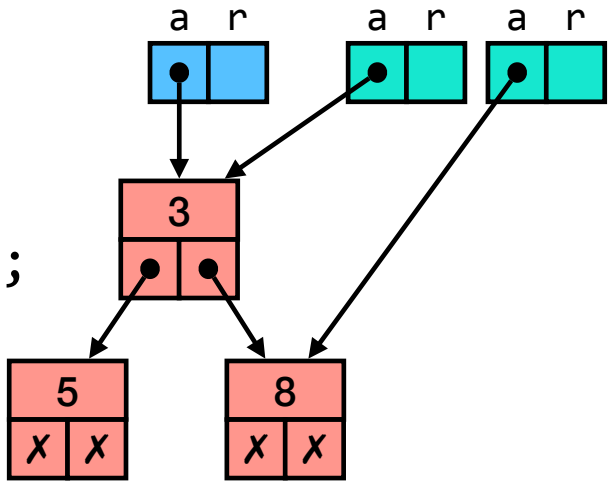
int main() {
  abin a = mkroot(3, mkroot(5, NULL, NULL), mkroot(8, NULL, NULL));
  int r = size(a);
  return 0;
}
```



Tamanho

```
int size(abin a) {
  int r;
  if (a == NULL) r = 0;
  else r = 1 + size(a->esq) + size(a->dir);
  return r;
}

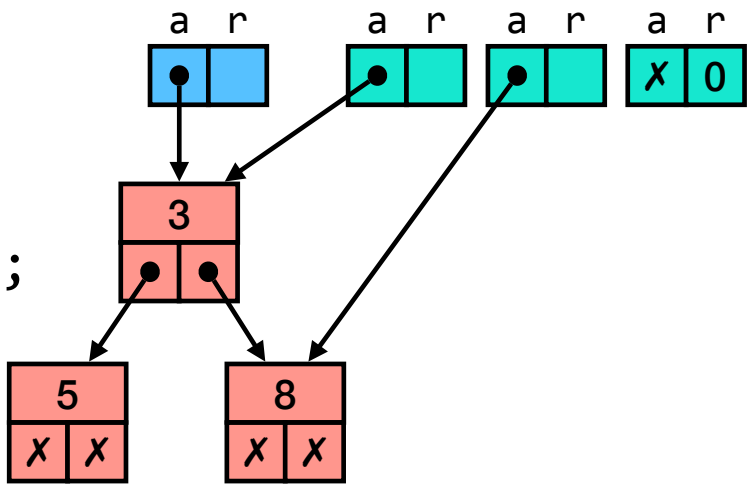
int main() {
  abin a = mkroot(3, mkroot(5, NULL, NULL), mkroot(8, NULL, NULL));
  int r = size(a);
  return 0;
}
```



Tamanho

```
int size(abin a) {
  int r;
  if (a == NULL) r = 0;
  else r = 1 + size(a->esq) + size(a->dir);
  return r;
}

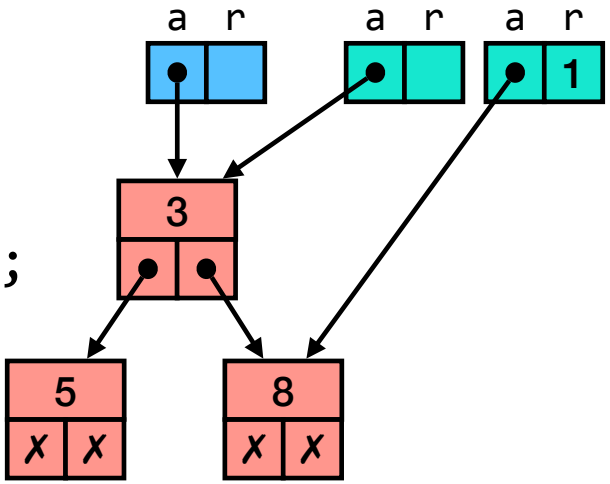
int main() {
  abin a = mkroot(3, mkroot(5, NULL, NULL), mkroot(8, NULL, NULL));
  int r = size(a);
  return 0;
}
```



Tamanho

```
int size(abin a) {
  int r;
  if (a == NULL) r = 0;
  else r = 1 + size(a->esq) + size(a->dir);
  return r;
}

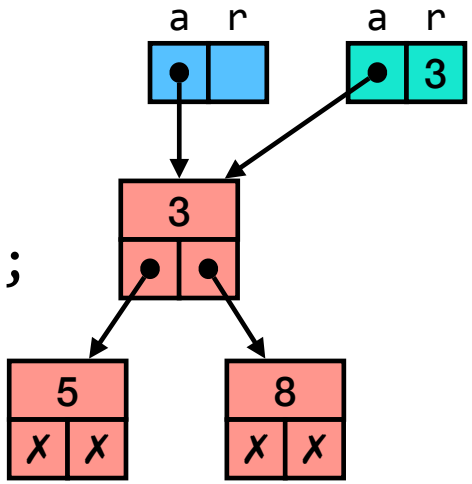
int main() {
  abin a = mkroot(3, mkroot(5, NULL, NULL), mkroot(8, NULL, NULL));
  int r = size(a);
  return 0;
}
```



Tamanho

```
int size(abin a) {
  int r;
  if (a == NULL) r = 0;
  else r = 1 + size(a->esq) + size(a->dir);
  return r;
}

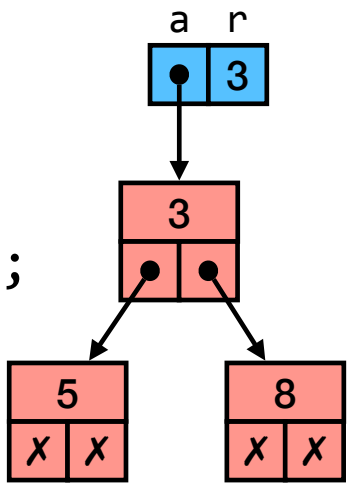
int main() {
  abin a = mkroot(3, mkroot(5, NULL, NULL), mkroot(8, NULL, NULL));
  int r = size(a);
  return 0;
}
```



Tamanho

```
int size(abin a) {
  int r;
  if (a == NULL) r = 0;
  else r = 1 + size(a->esq) + size(a->dir);
  return r;
}

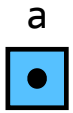
int main() {
  abin a = mkroot(3, mkroot(5, NULL, NULL), mkroot(8, NULL, NULL));
  int r = size(a);
  return 0;
}
```



Criação a partir de array

```
abin fromArray(int v[], int N) {
  abin a = NULL;
  for (int i = 0; i < N; i++) a = mkroot(v[i], a, NULL);
  return a;
}

int main() {
  int v[] = {5,3,8};
  abin a = fromArray(v, 3);
  return 0;
}
```



Criação a partir de array

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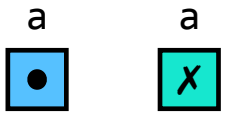
  abin a = NULL;
  for (int i = 0; i < N; i++) a = mkroot(v[i], a, NULL);
  return a;
}

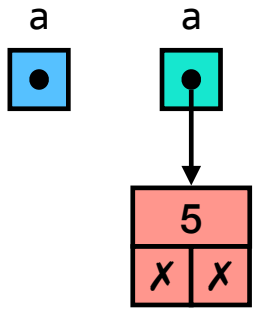
int main() {
  int v[] = {5,3,8};
  abin a = fromArray(v, 3);
  return 0;
}
```



Criação a partir de array

```
abin fromArray(int v[], int N) {
  abin a = NULL;
  for (int i = 0; i < N; i++) a = mkroot(v[i], a, NULL);
  return a;
}

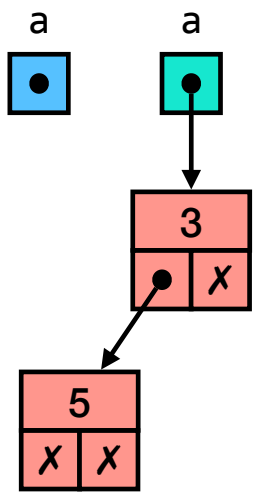
int main() {
  int v[] = {5,3,8};
  abin a = fromArray(v, 3);
  return 0;
}
```



Criação a partir de array

```
abin fromArray(int v[], int N) {
  abin a = NULL;
  for (int i = 0; i < N; i++) a = mkroot(v[i], a, NULL);
  return a;
}

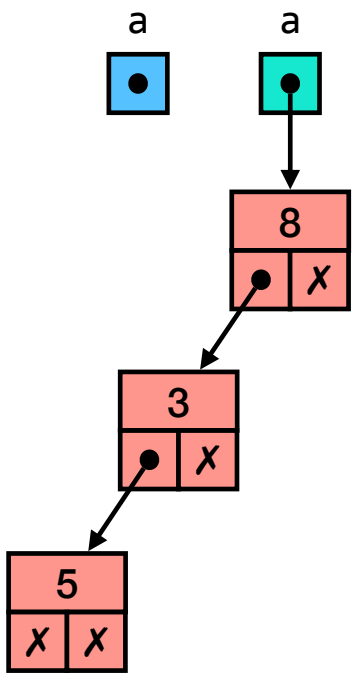
int main() {
  int v[] = {5,3,8};
  abin a = fromArray(v, 3);
  return 0;
}
```



Criação a partir de array

```
abin fromArray(int v[], int N) {
  abin a = NULL;
  for (int i = 0; i < N; i++) a = mkroot(v[i], a, NULL);
  return a;
}

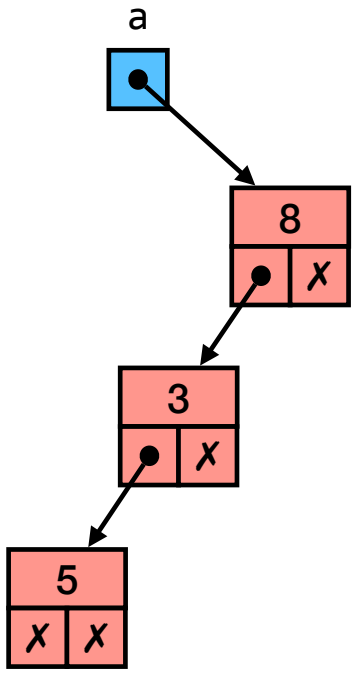
int main() {
  int v[] = {5,3,8};
  abin a = fromArray(v, 3);
  return 0;
}
```



Criação a partir de array

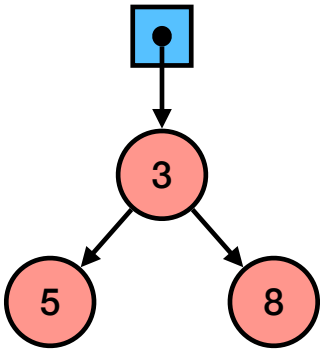
```
abin fromArray(int v[], int N) {
  abin a = NULL;
  for (int i = 0; i < N; i++) a = mkroot(v[i], a, NULL);
  return a;
}

int main() {
  int v[] = {5,3,8};
  abin a = fromArray(v, 3);
  return 0;
}
```

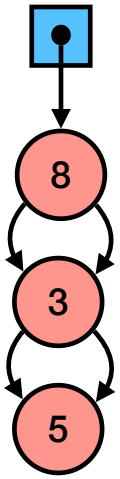


#26 Que árvore vai ser criada?

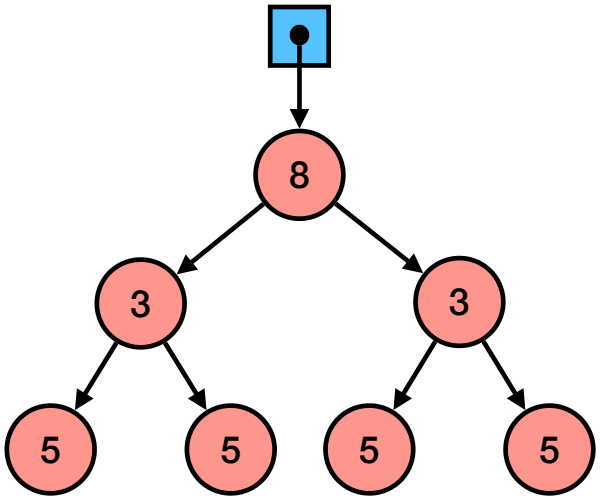
```
int v[] = {5,3,8}; abin a = NULL;
for (int i = 0; i < N; i++) a = mkroot(v[i], a, a);
```



A

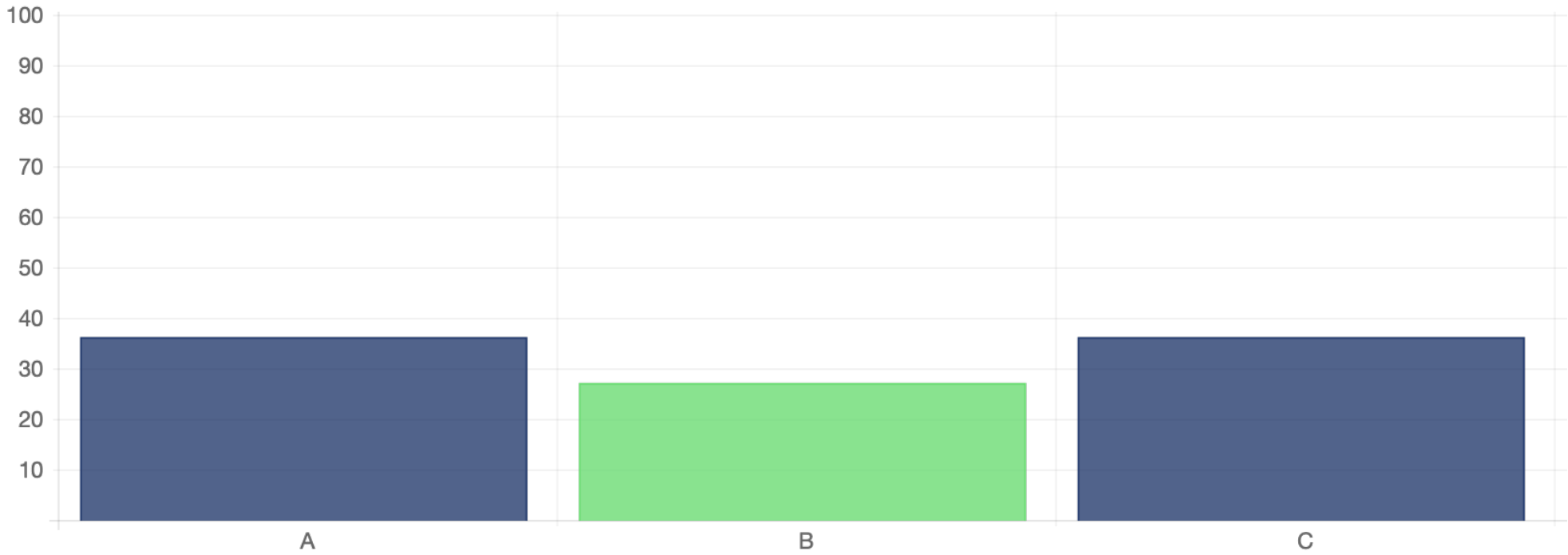


B



C

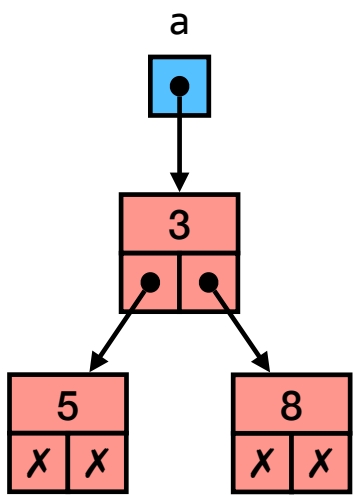
#26 Que árvore vai ser criada?



Criação a partir de array

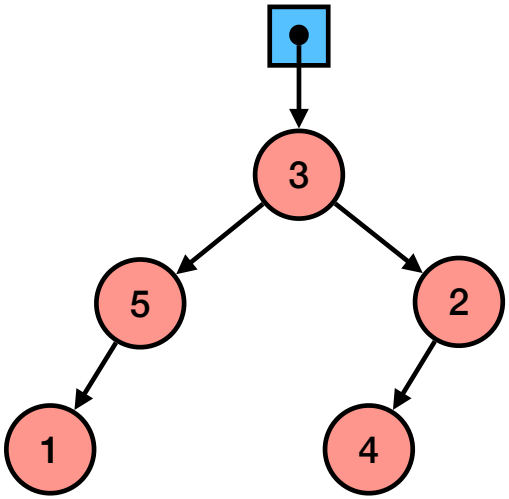
```
abin fromArray(int v[], int N) {
  abin a;
  if (N == 0) a = NULL;
  else {
    int m = N / 2;
    abin l = fromArray(v, m);
    abin r = fromArray(v+m+1, N-m-1);
    a = mkroot(v[m], l, r);
  }
  return a;
}
```

```
int main() {
  int v[] = {5,3,8};
  abin a = fromArray(v, 3);
  return 0;
}
```

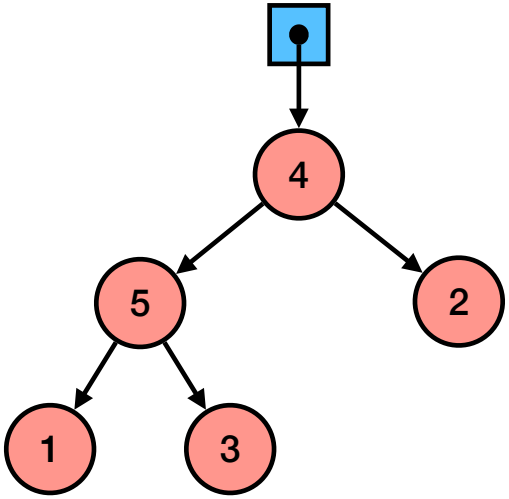


#27 Que árvore balanceada vai ser criada?

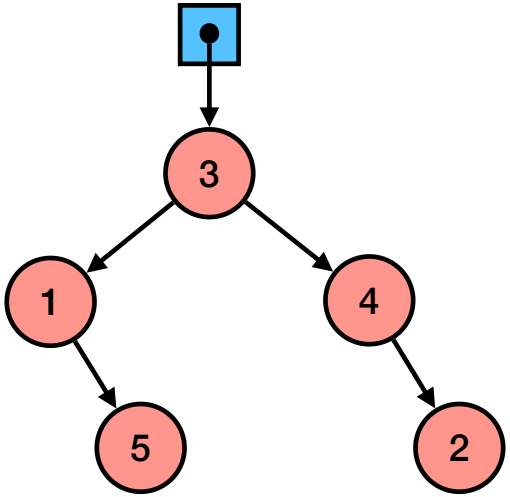
```
int v[] = {1,5,3,4,2}; abin a = fromArray(v, 5);
```



A

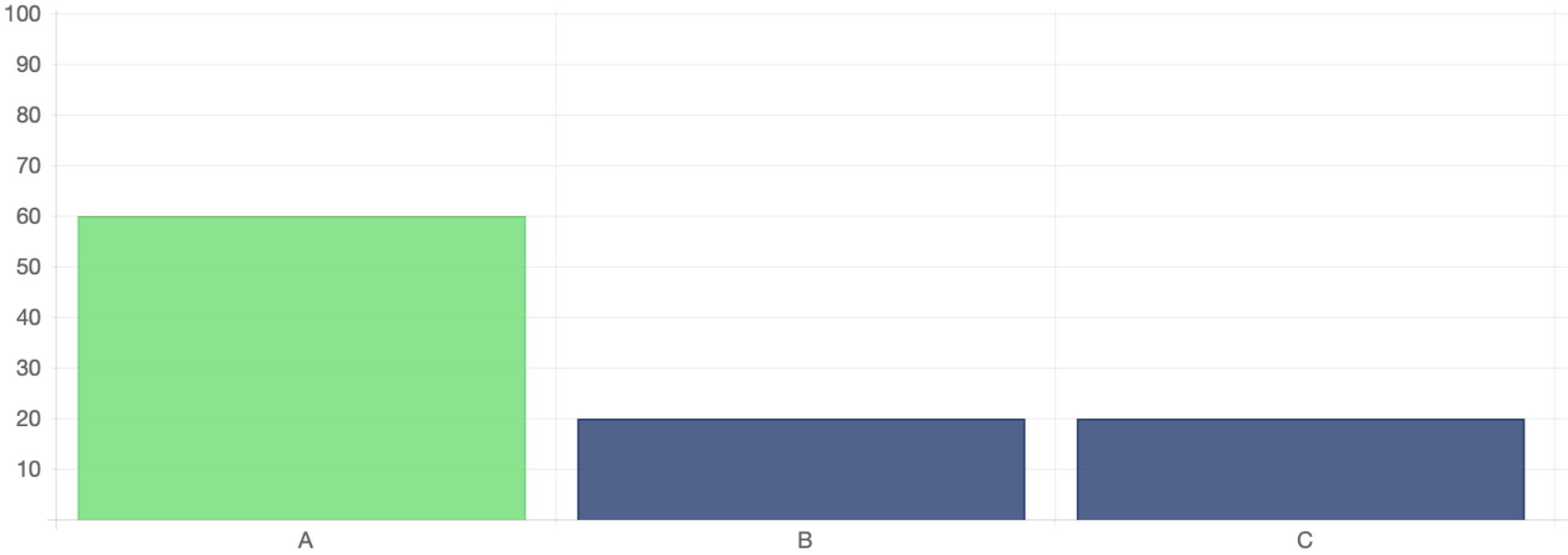


B



C

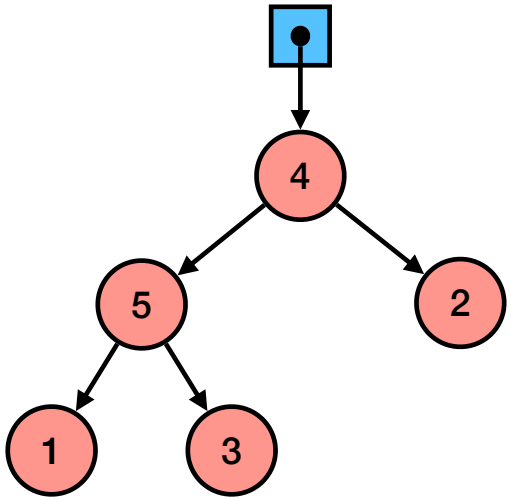
#27 Que árvore balanceada vai ser criada?



Aula 20

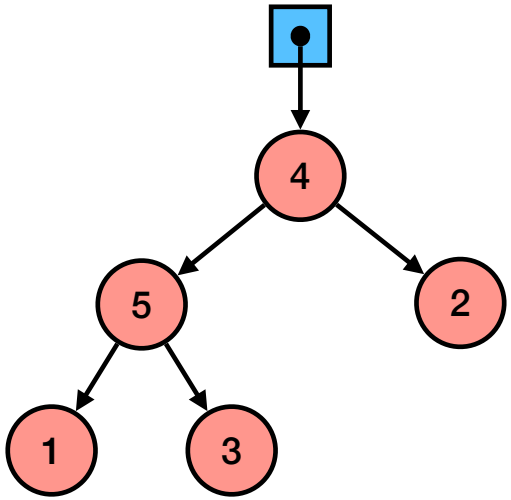
Travessia inorder

```
void inorder(abin a) {
  if (a == NULL) return;
  inorder(a->esq);
  printf("%d\n", a->valor);
  inorder(a->dir);
}
```



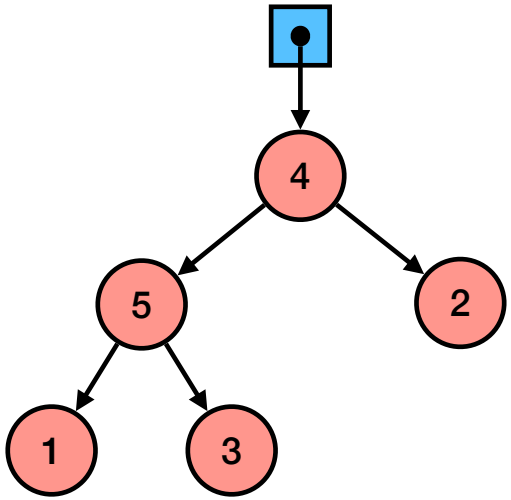
Travessia preorder

```
void preorder(abin a) {
  if (a == NULL) return;
  printf("%d\n", a->valor);
  preorder(a->esq);
  preorder(a->dir);
}
```



Travessia postorder

```
void postorder(abin a) {
  if (a == NULL) return;
  postorder(a->esq);
  postorder(a->dir);
  printf("%d\n", a->valor);
}
```



Copiar para array inorder

```
int toArrayInorder(abin a, int v[]) {
  int l, r;
  if (a == NULL) return 0;
  l = toArrayInorder(a->esq, v);
  v[l] = a->valor;
  r = toArrayInorder(a->dir, v+1+l);
  return 1+l+r;
}
```

Copiar para array preorder

```
int toArrayPreorder(abin a, int v[]) {
  int l, r;
  if (a == NULL) return 0;
  v[0] = a->valor;
  l = toArrayPreorder(a->esq, v+1);
  r = toArrayPreorder(a->dir, v+1+l);
  return 1+l+r;
}
```

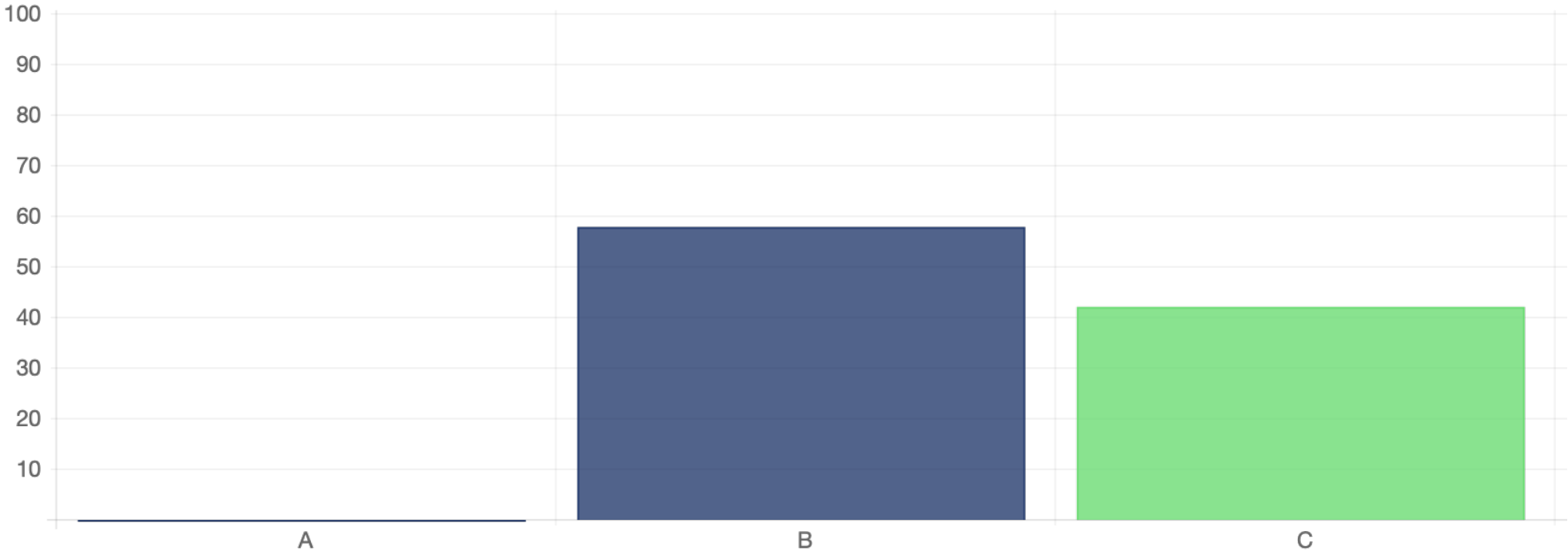
#29 Como copiar para array postorder?

```
int A(abin a, int v[]) {
  int l, r;
  if (a == NULL) return 0;
  l = A(a->esq, v+1);
  r = A(a->dir, v+1+l);
  v[0] = a->valor;
  return 1+l+r;
}
```

```
int B(abin a, int v[]) {
  int l, r;
  if (a == NULL) return 0;
  l = B(a->esq, v);
  r = B(a->dir, v+l);
  v[1+l+r] = a->valor;
  return 1+l+r;
}
```

```
int C(abin a, int v[]) {
  int l, r;
  if (a == NULL) return 0;
  l = C(a->esq, v);
  r = C(a->dir, v+l);
  v[l+r] = a->valor;
  return 1+l+r;
}
```

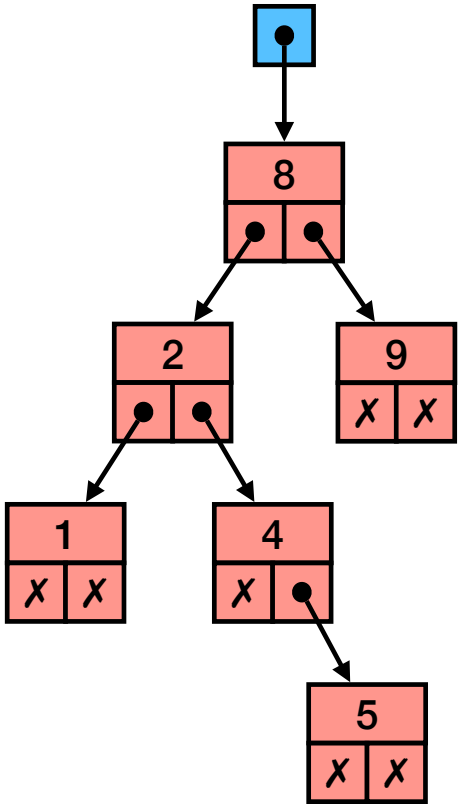
#29 Como copiar para array postorder?



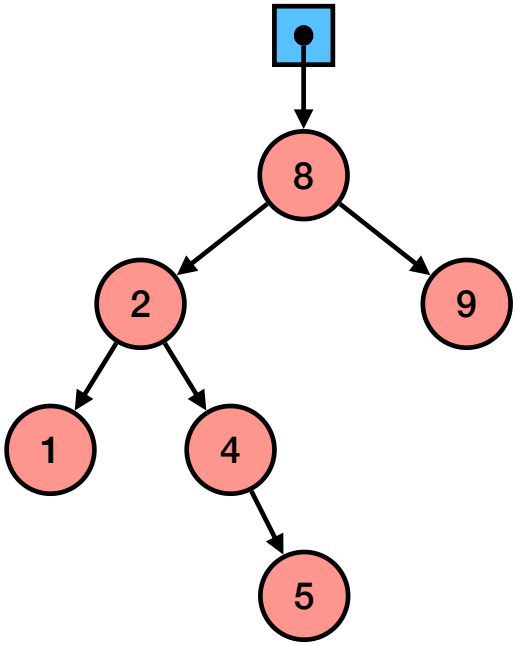
Pesquisa

```
abin search(int x, abin a) {
  abin r;
  if (a == NULL) return NULL;
  if (a->valor == x) return a;
  r = search(x, a->esq);
  if (r == NULL) return search(x, a->dir);
  return r;
}
```

Árvores binárias de procura



Árvores binárias de procura



Pesquisa ordenada

```
abin search(int x, abin a) {
  if (a == NULL) return NULL;
  if (a->valor == x) return a;
  if (a->valor > x) return search(x, a->esq);
  else return search(x, a->dir);
}
```

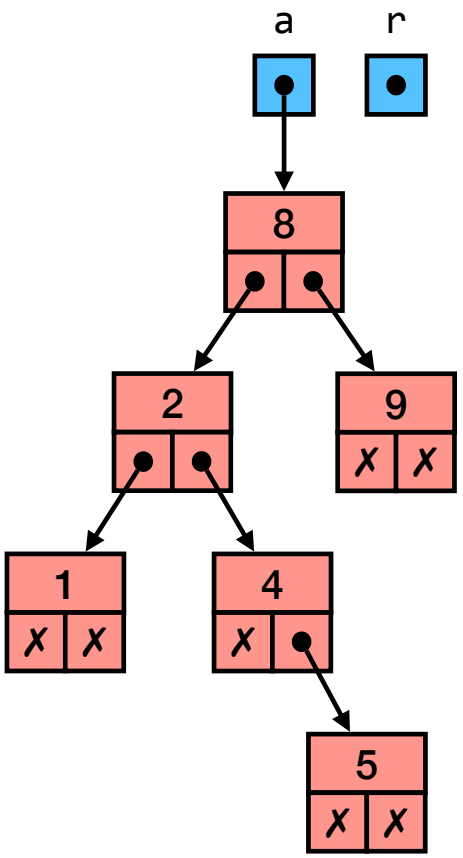
Pesquisa ordenada

```
abin search(int x, abin a) {
  while (a != NULL && a->valor != x) {
    if (a->valor > x) a = a->esq;
    else a = a->dir;
  }
  return a;
}
```

Pesquisa ordenada

```
abin search(int x, abin a) {
  while (a != NULL && a->valor != x) {
    if (a->valor > x) a = a->esq;
    else a = a->dir;
  }
  return a;
}

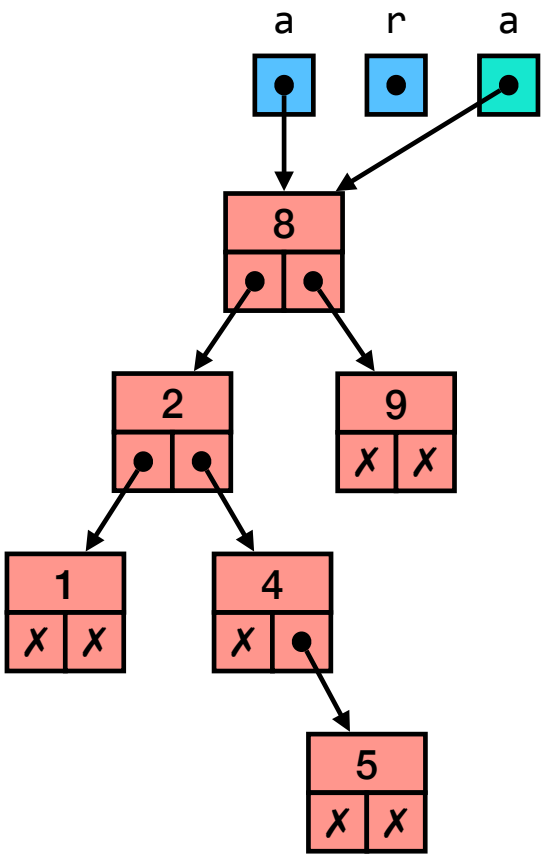
int main() {
  abin a = …;
  abin r = search(5, a);
  return 0;
}
```



Pesquisa ordenada

```
abin search(int x, abin a) {
  while (a != NULL && a->valor != x) {
    if (a->valor > x) a = a->esq;
    else a = a->dir;
  }
  return a;
}

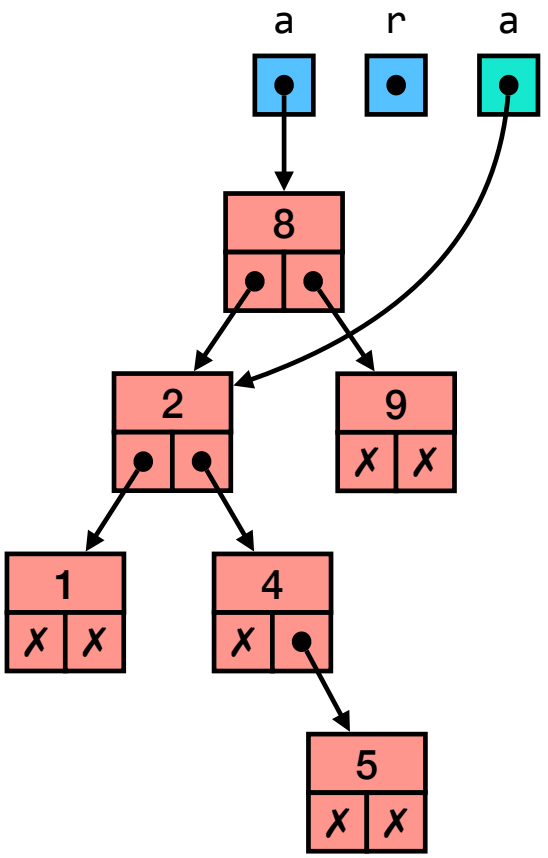
int main() {
  abin a = …;
  abin r = search(5, a);
  return 0;
}
```



Pesquisa ordenada

```
abin search(int x, abin a) {
  while (a != NULL && a->valor != x) {
    if (a->valor > x) a = a->esq;
    else a = a->dir;
  }
  return a;
}

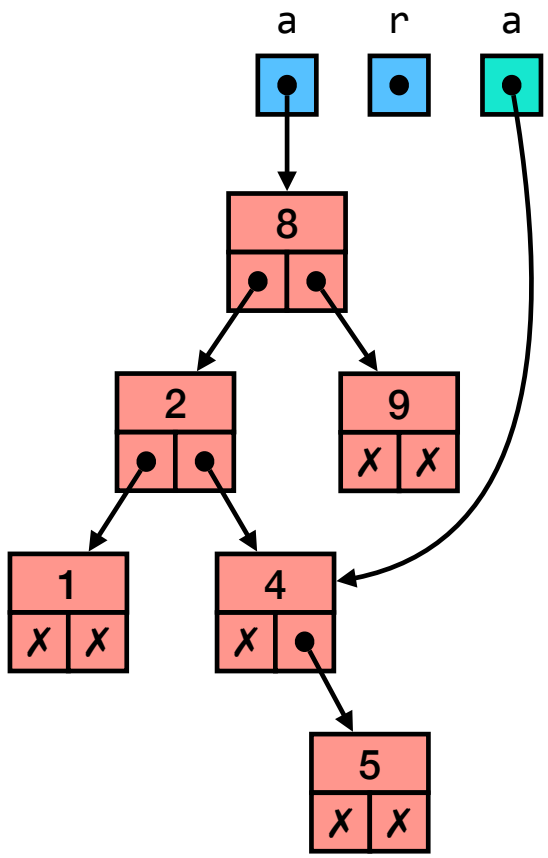
int main() {
  abin a = …;
  abin r = search(5, a);
  return 0;
}
```



Pesquisa ordenada

```
abin search(int x, abin a) {
  while (a != NULL && a->valor != x) {
    if (a->valor > x) a = a->esq;
    else a = a->dir;
  }
  return a;
}

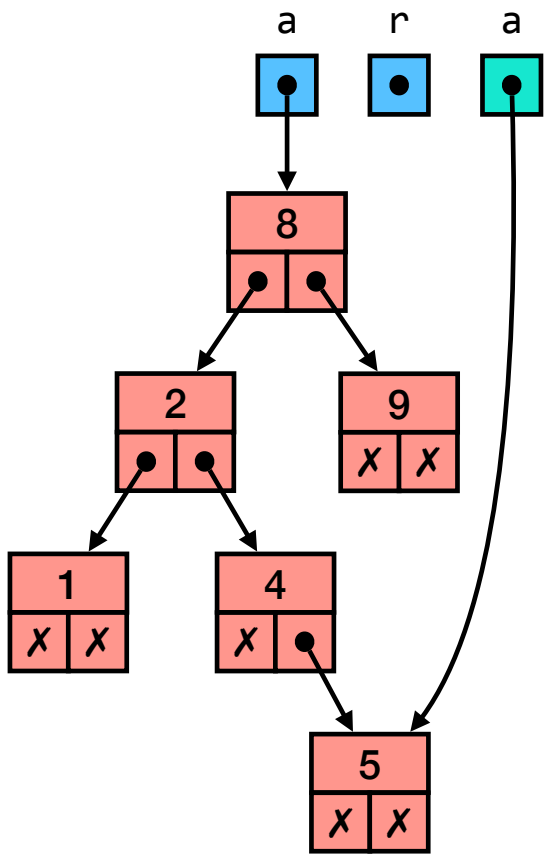
int main() {
  abin a = …;
  abin r = search(5, a);
  return 0;
}
```



Pesquisa ordenada

```
abin search(int x, abin a) {
  while (a != NULL && a->valor != x) {
    if (a->valor > x) a = a->esq;
    else a = a->dir;
  }
  return a;
}

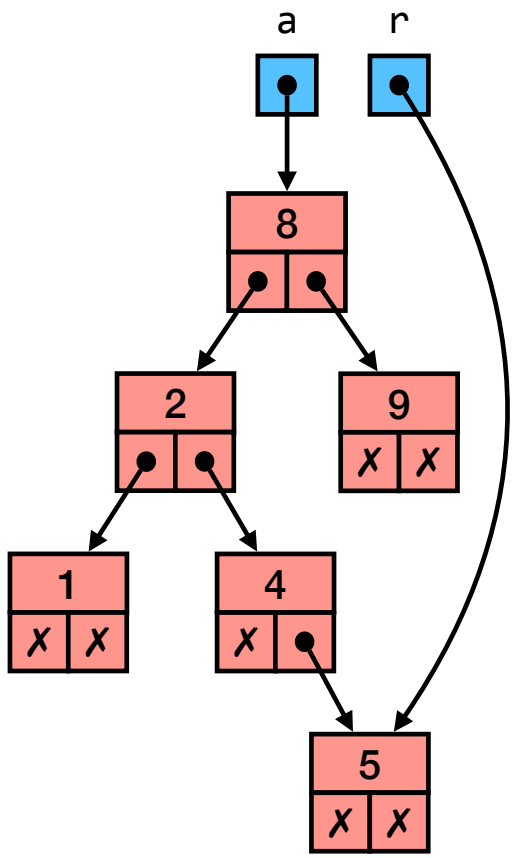
int main() {
  abin a = …;
  abin r = search(5, a);
  return 0;
}
```



Pesquisa ordenada

```
abin search(int x, abin a) {
  while (a != NULL && a->valor != x) {
    if (a->valor > x) a = a->esq;
    else a = a->dir;
  }
  return a;
}

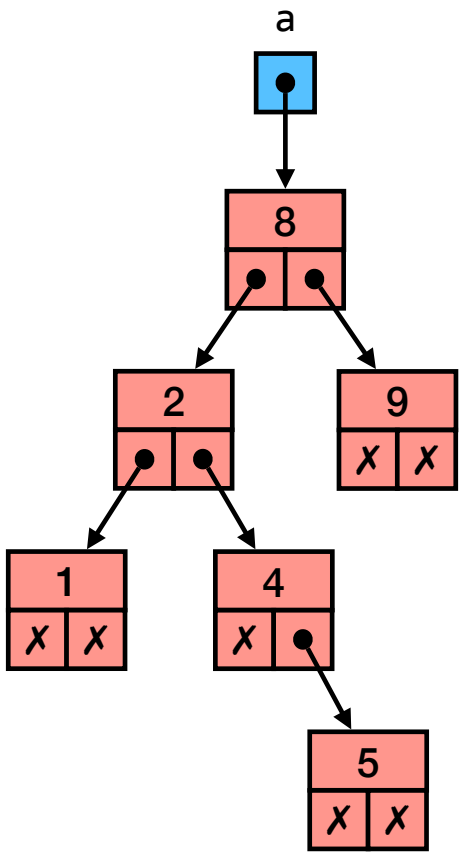
int main() {
  abin a = …;
  abin r = search(5, a);
  return 0;
}
```



Aula 21

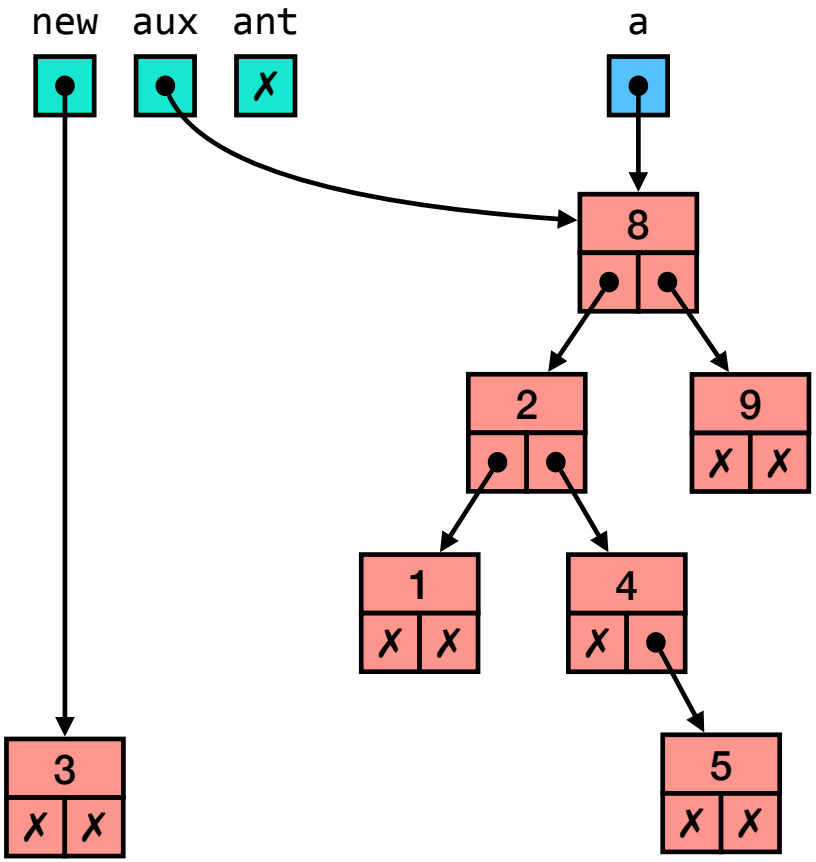
Inserção ordenada

```
int main() {
  abin a = …;
  a = insert(3, a);
  return 0;
}
```



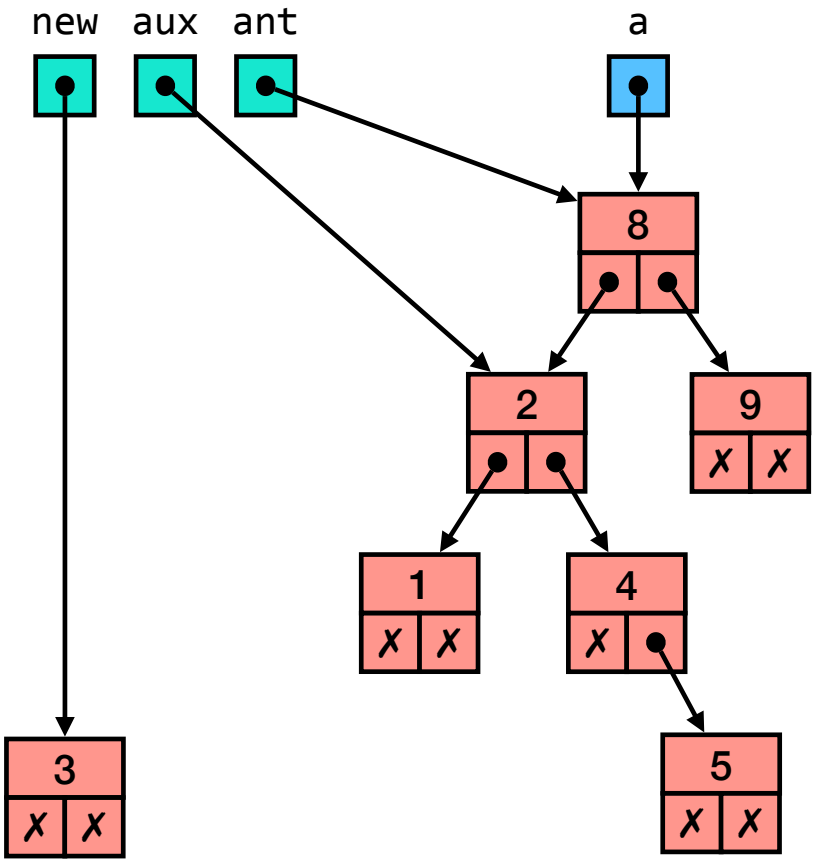
Inserção ordenada

```
int main() {
  abin a = …;
  a = insert(3, a);
  return 0;
}
```



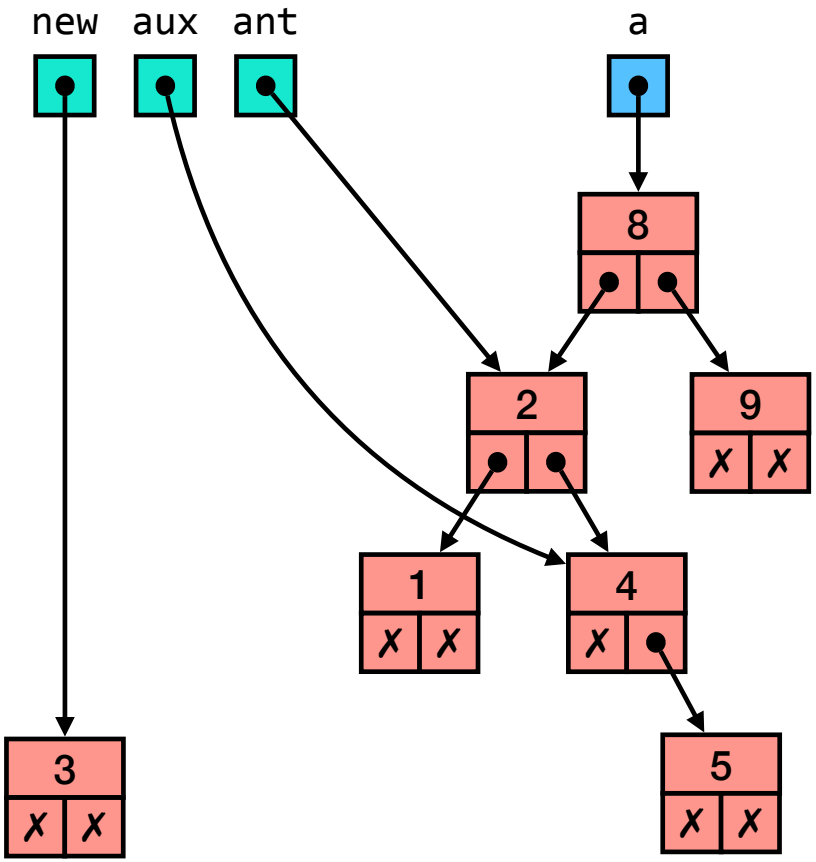
Inserção ordenada

```
int main() {
  abin a = …;
  a = insert(3, a);
  return 0;
}
```



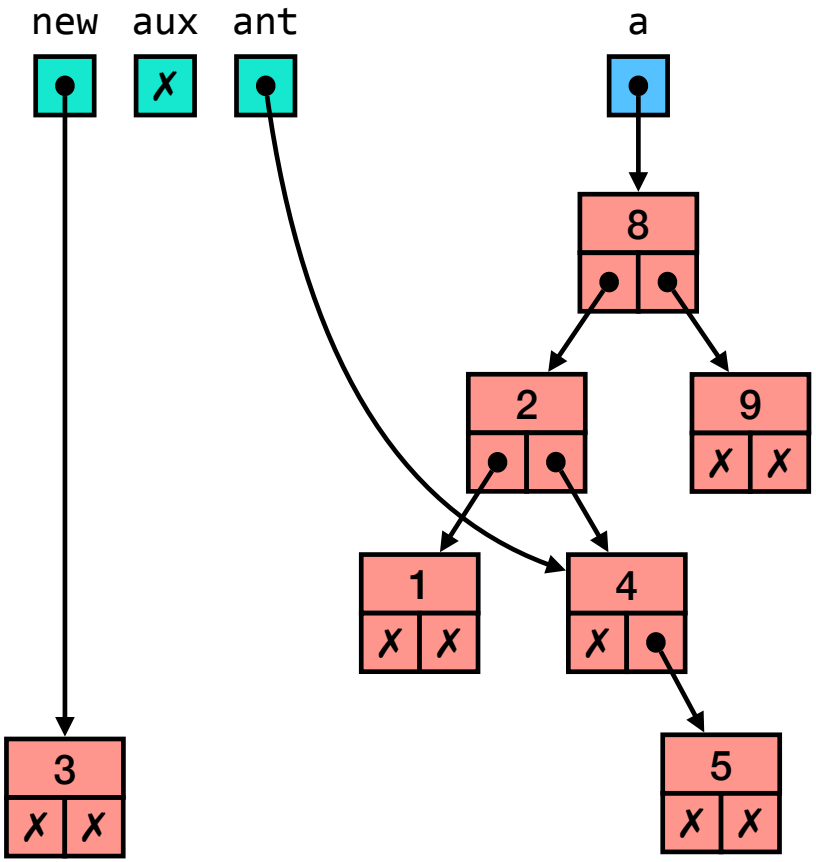
Inserção ordenada

```
int main() {
  abin a = …;
  a = insert(3, a);
  return 0;
}
```



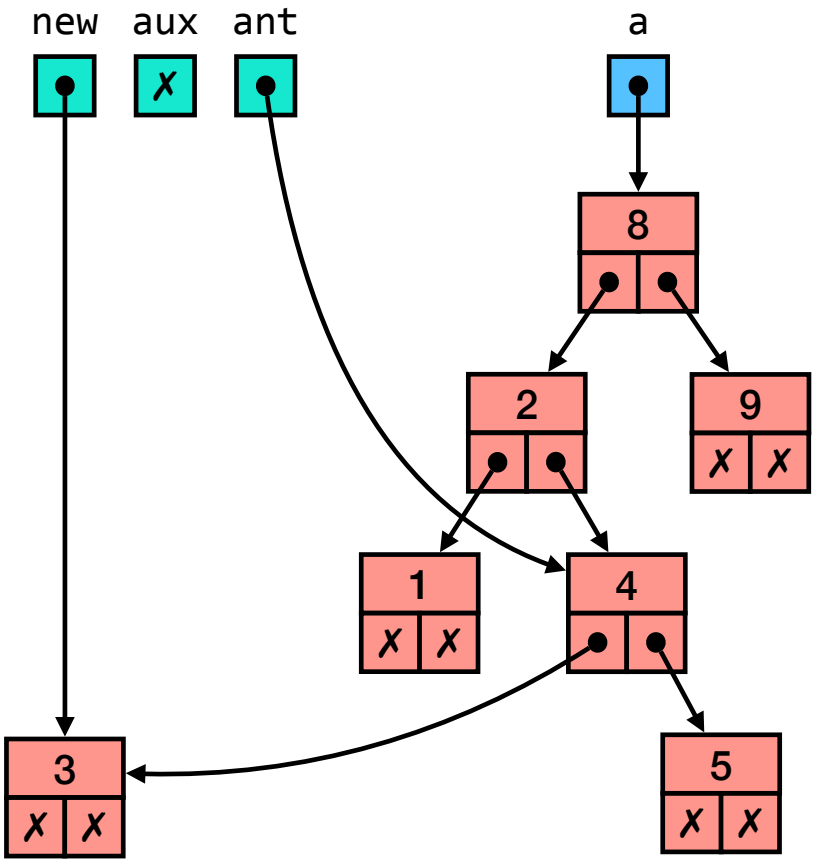
Inserção ordenada

```
int main() {
  abin a = …;
  a = insert(3, a);
  return 0;
}
```



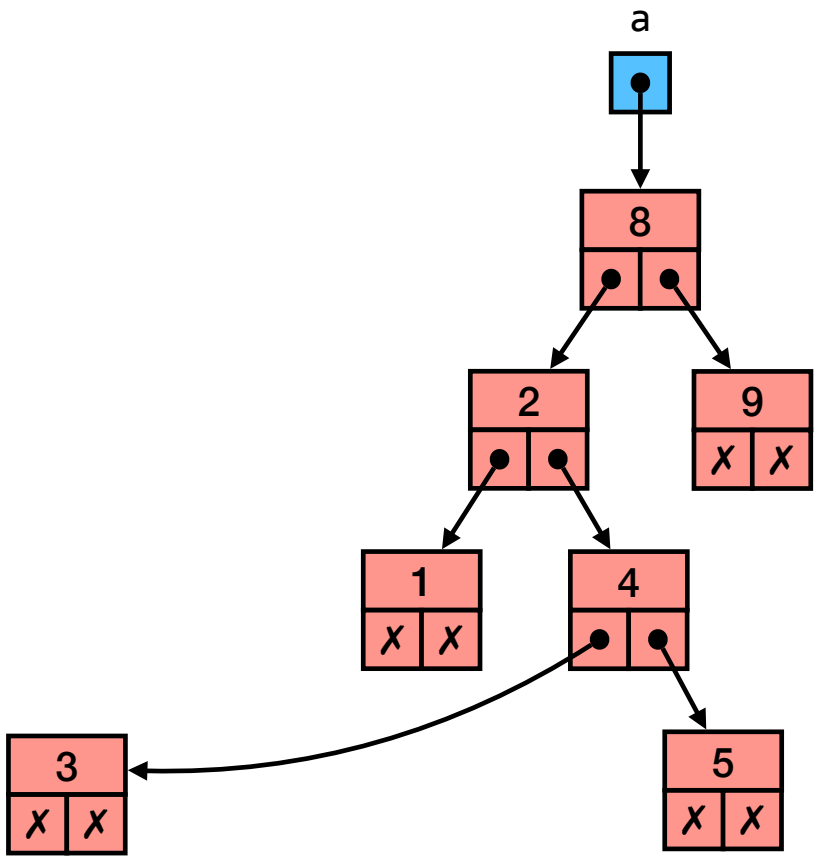
Inserção ordenada

```
int main() {
  abin a = …;
  a = insert(3, a);
  return 0;
}
```



Inserção ordenada

```
int main() {
  abin a = …;
  a = insert(3, a);
  return 0;
}
```

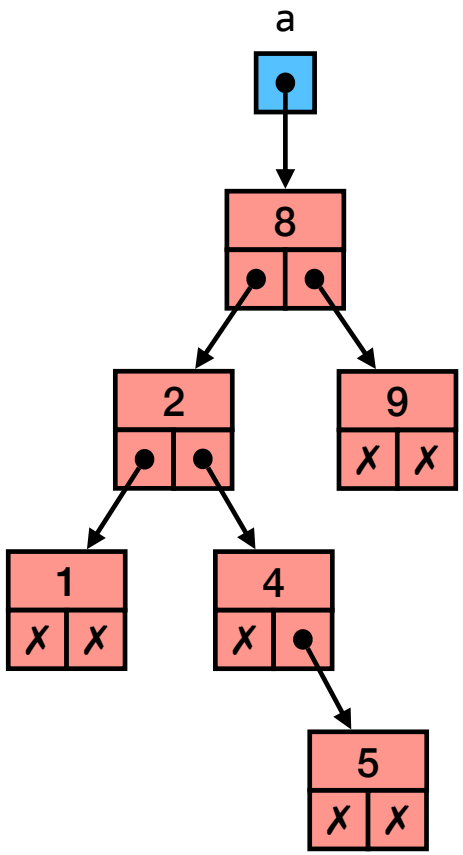


Inserção ordenada

```
abin insert(int x, abin a) {
  abin ant = NULL, aux = a, new = mkroot(x, NULL, NULL);
  while (aux != NULL) {
    ant = aux;
    if (aux->valor > x) aux = aux->esq;
    else aux = aux->dir;
  }
  if (ant == NULL) a = new;
  else if (ant->valor > x) ant->esq = new;
  else ant->dir = new;
  return a;
}
```

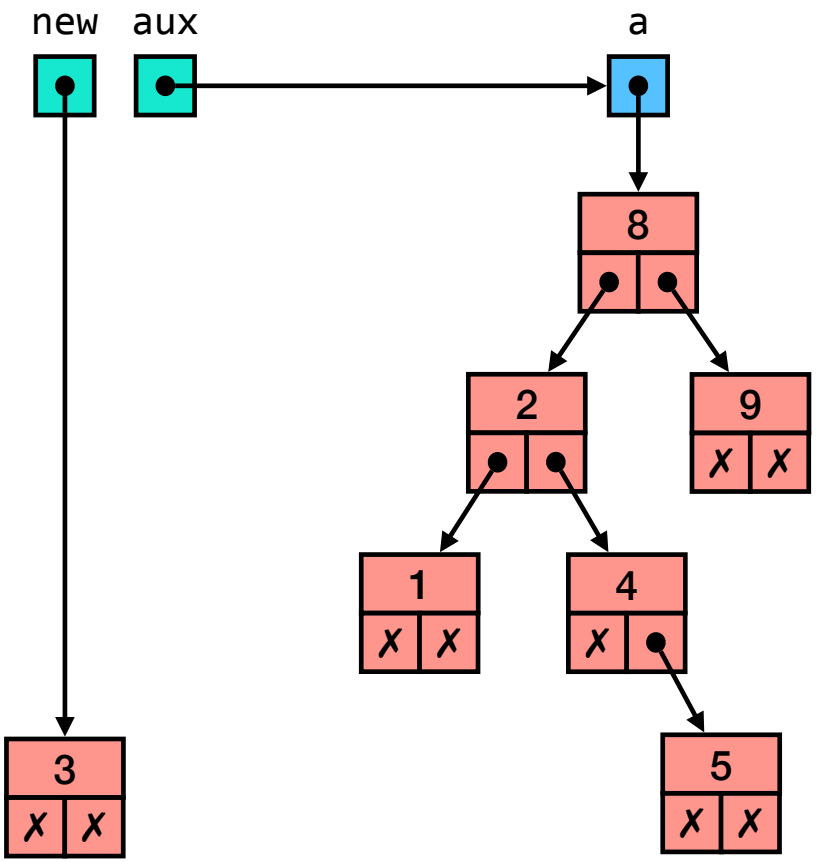
Inserção ordenada

```
int main() {
  abin a = …;
  a = insert(3, a);
  return 0;
}
```



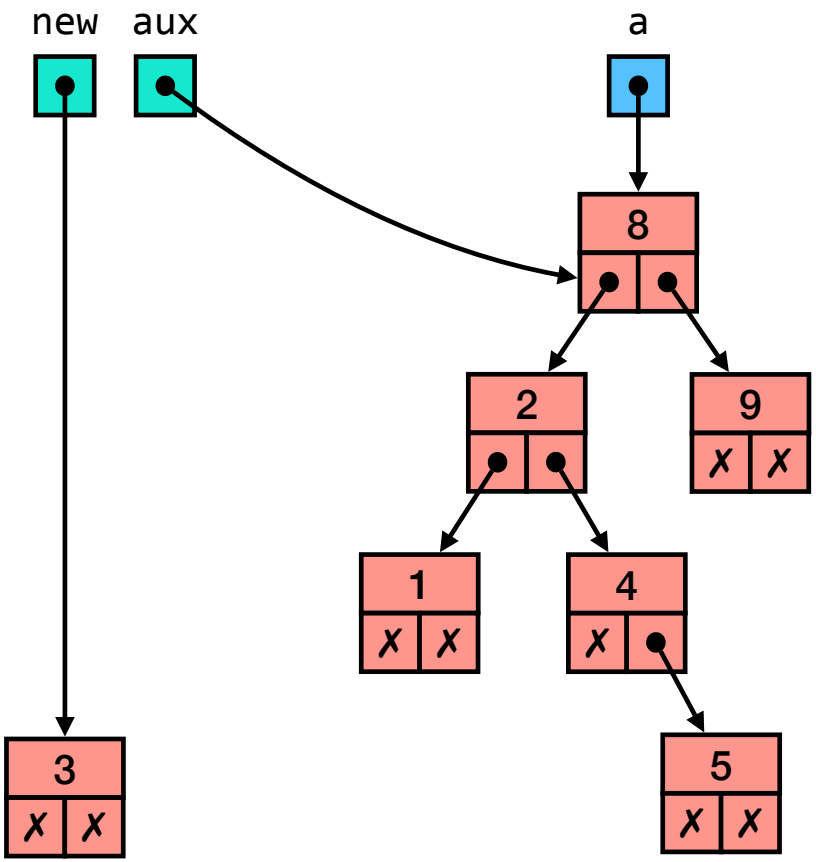
Inserção ordenada

```
int main() {
  abin a = …;
  a = insert(3, a);
  return 0;
}
```



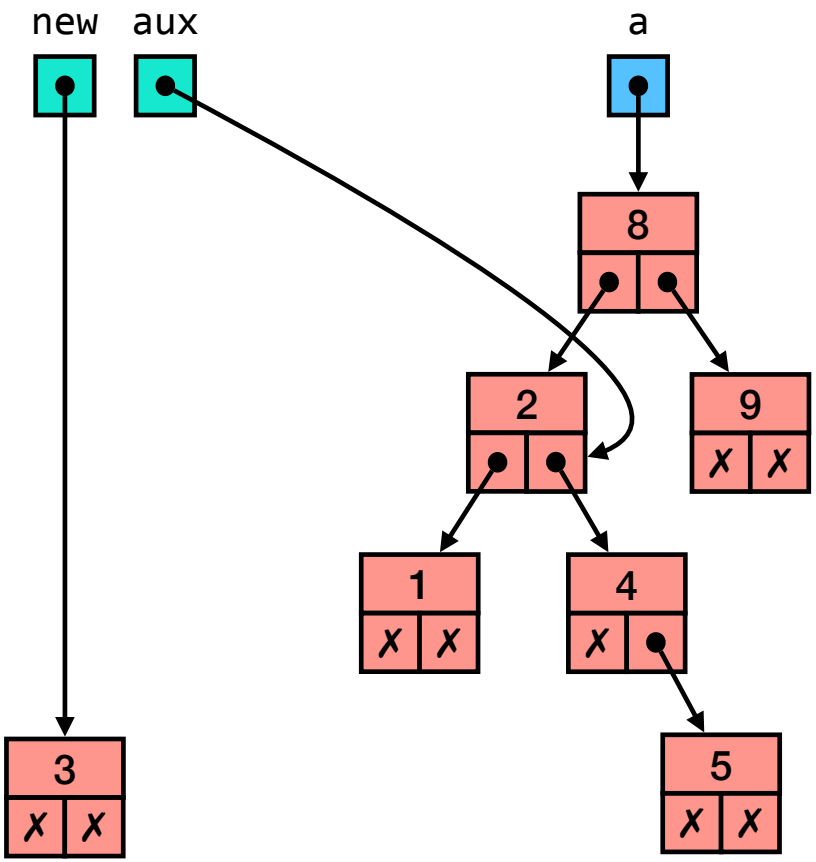
Inserção ordenada

```
int main() {
  abin a = …;
  a = insert(3, a);
  return 0;
}
```



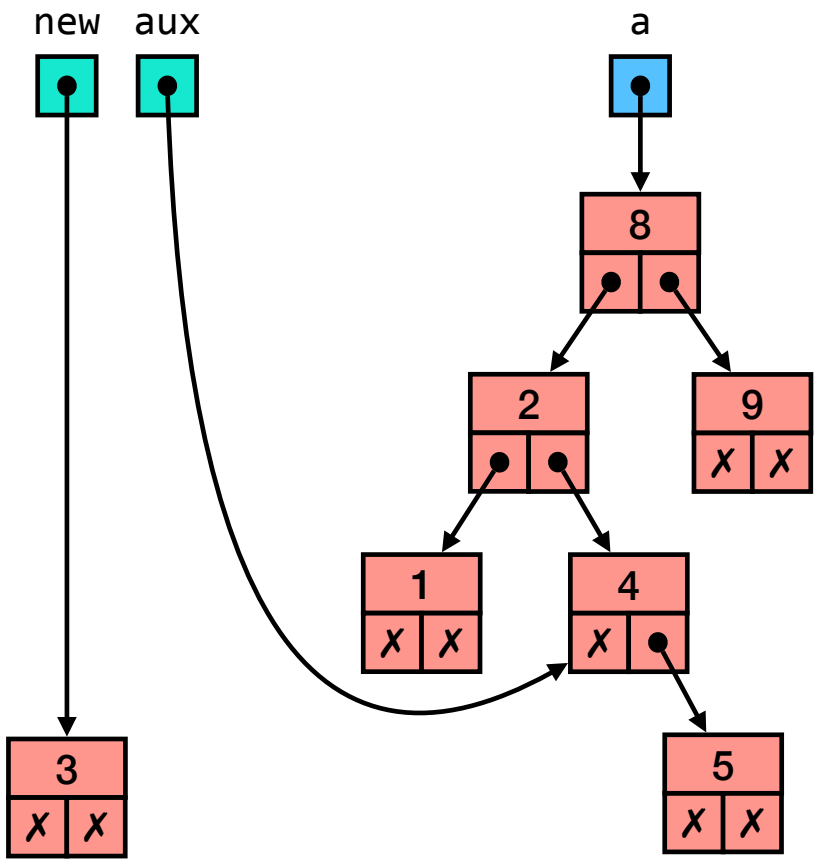
Inserção ordenada

```
int main() {
  abin a = …;
  a = insert(3, a);
  return 0;
}
```



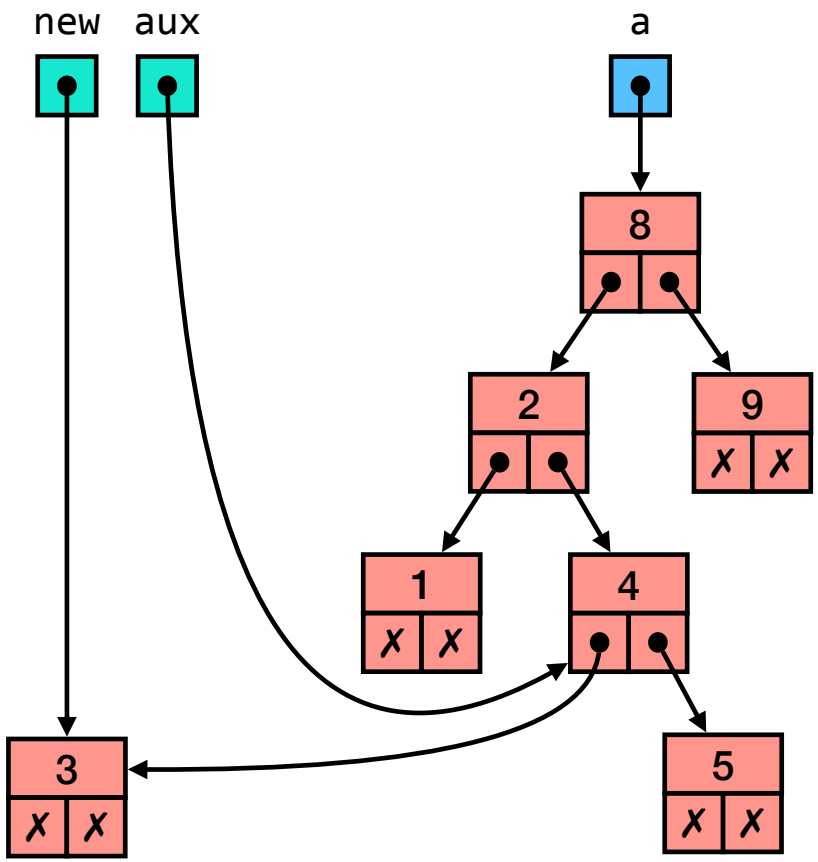
Inserção ordenada

```
int main() {
  abin a = …;
  a = insert(3, a);
  return 0;
}
```



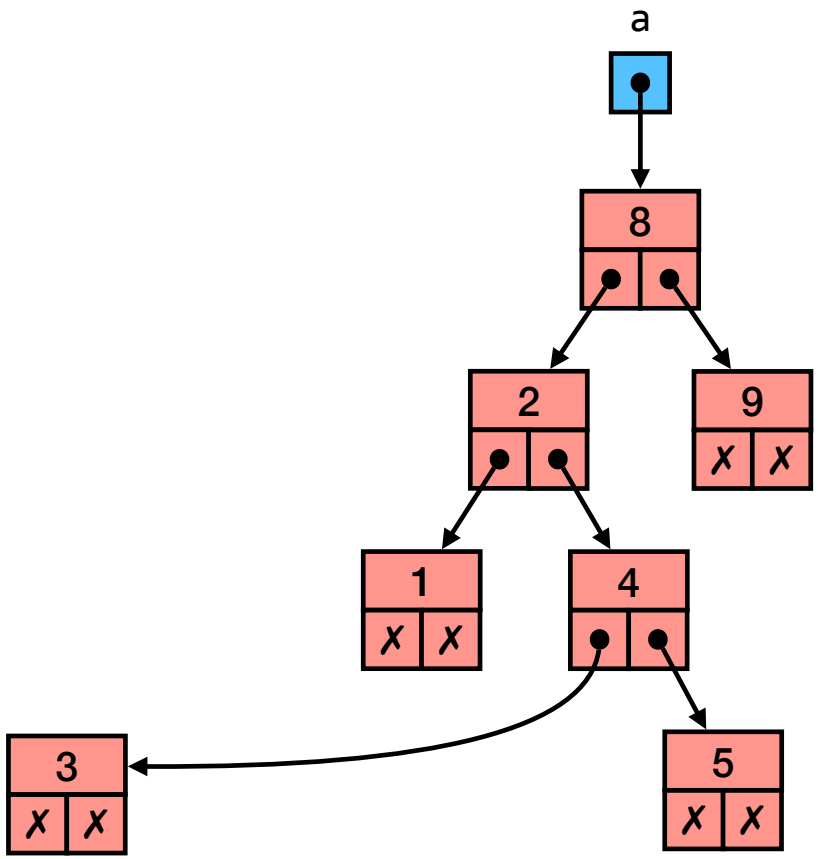
Inserção ordenada

```
int main() {
  abin a = …;
  a = insert(3, a);
  return 0;
}
```



Inserção ordenada

```
int main() {
  abin a = …;
  a = insert(3, a);
  return 0;
}
```

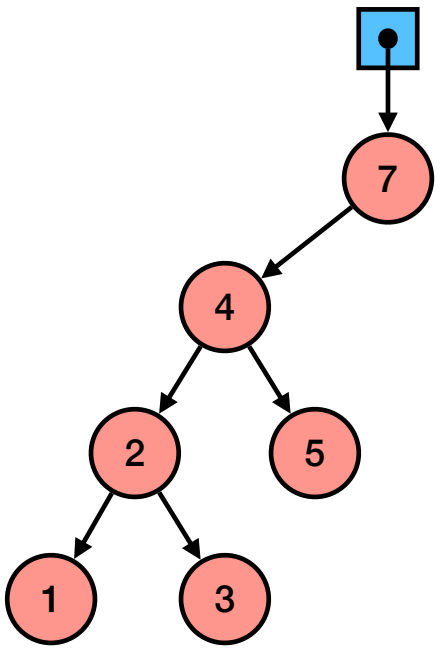


Inserção ordenada

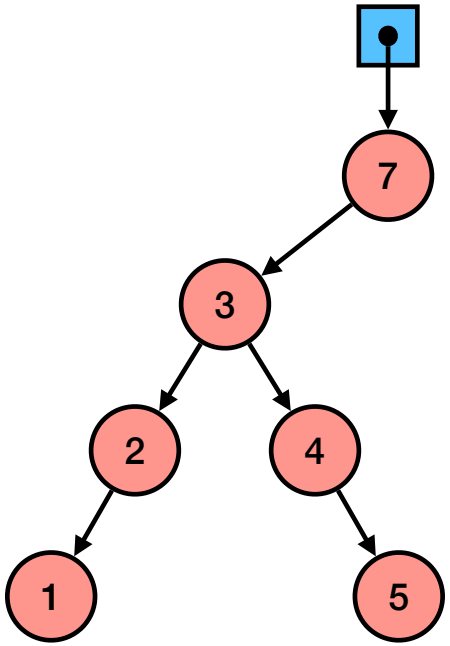
```
abin insert(int x, abin a) {
  abin *aux = &a, new = mkroot(x, NULL, NULL);
  while (*aux != NULL) {
    if ((*aux)->valor > x) aux = &(*aux)->esq;
    else aux = &(*aux)->dir;
  }
  *aux = new;
  return a;
}
```

#30 Que árvore de procura vai ser criada?

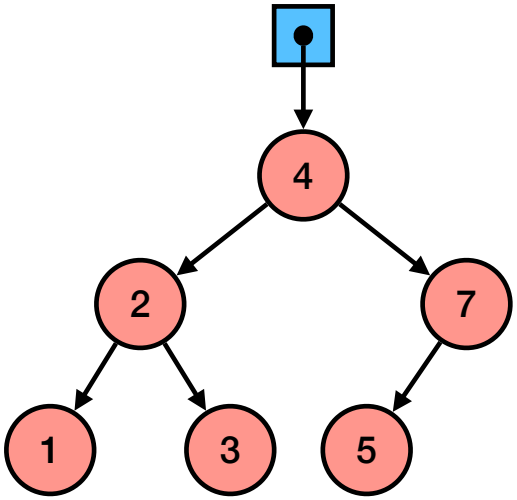
```
int v[] = {7,3,4,5,2,1}; abin a = NULL;
for (int i = 0; i < 6; i++) a = insert(v[i], a);
```



A

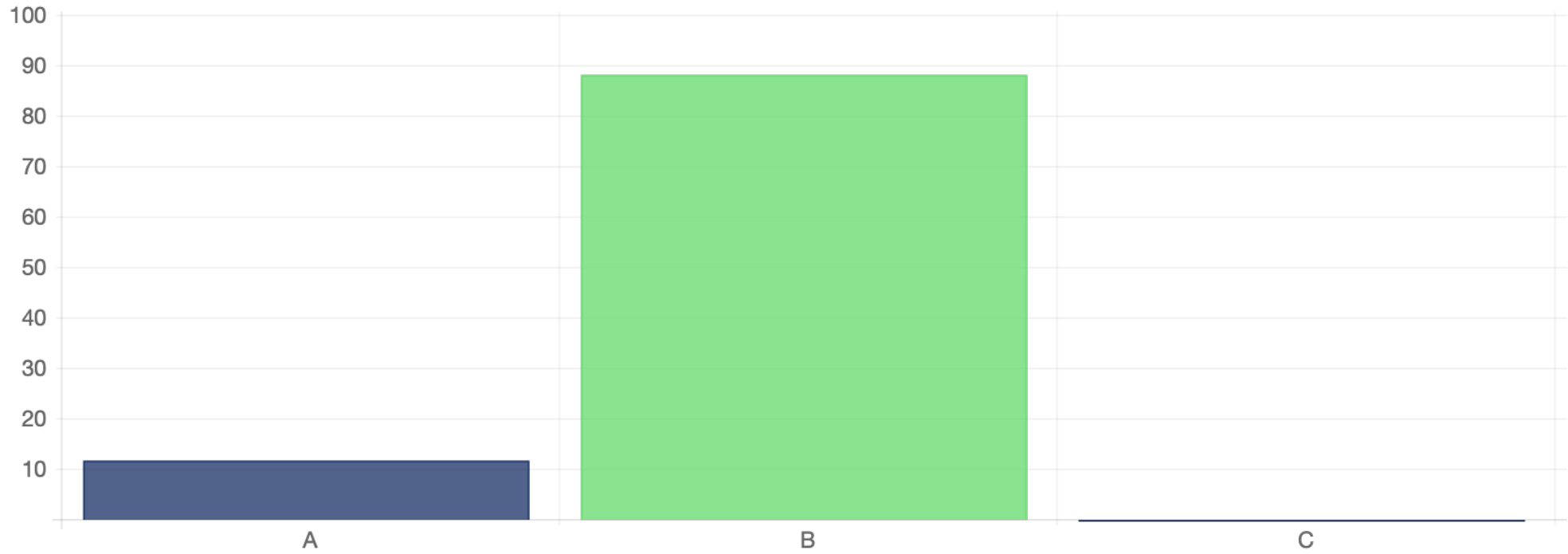


B



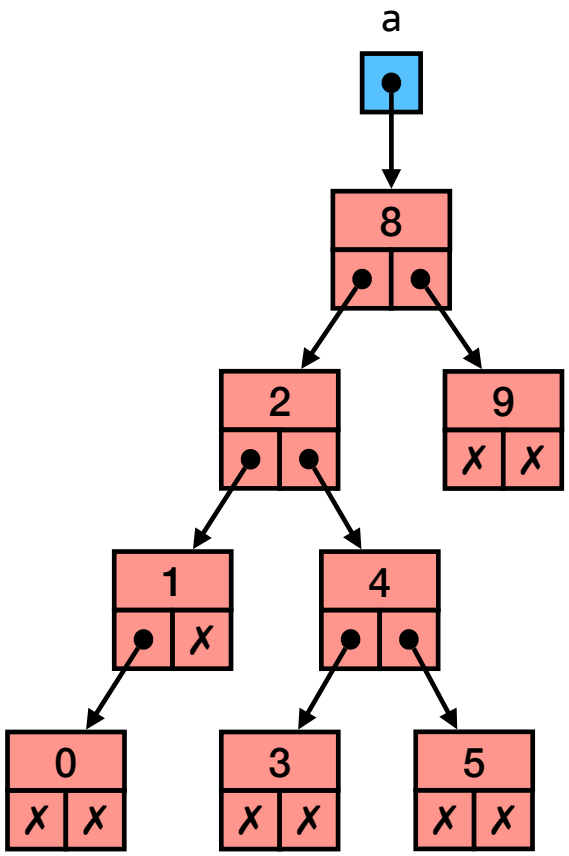
C

#30 Que árvore de procura vai ser criada?



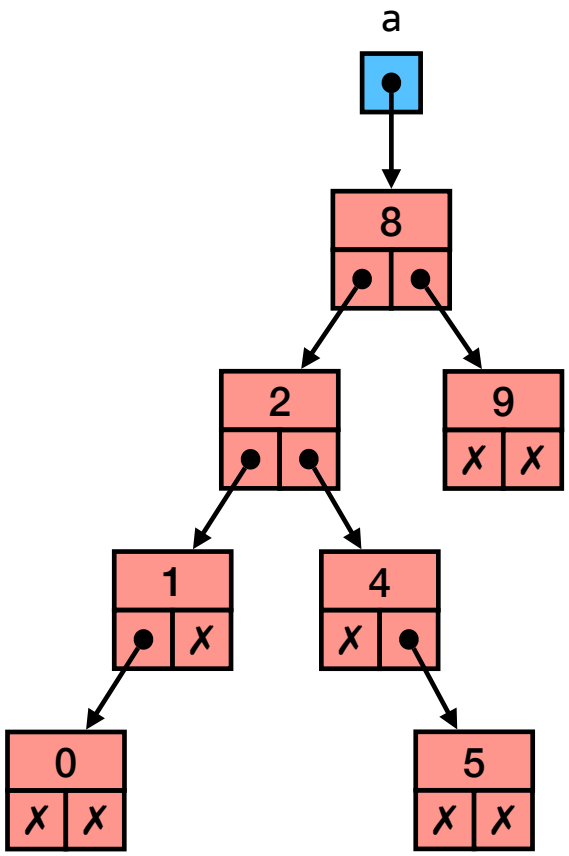
Remoção ordenada

```
int main() {
  abin a = …;
  a = delete(3, a);
  return 0;
}
```



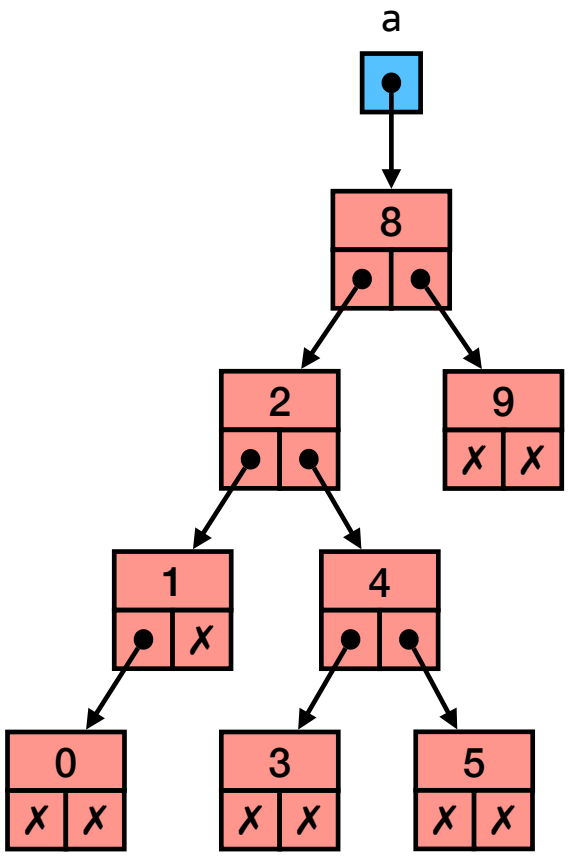
Remoção ordenada

```
int main() {
  abin a = …;
  a = delete(3, a);
  return 0;
}
```



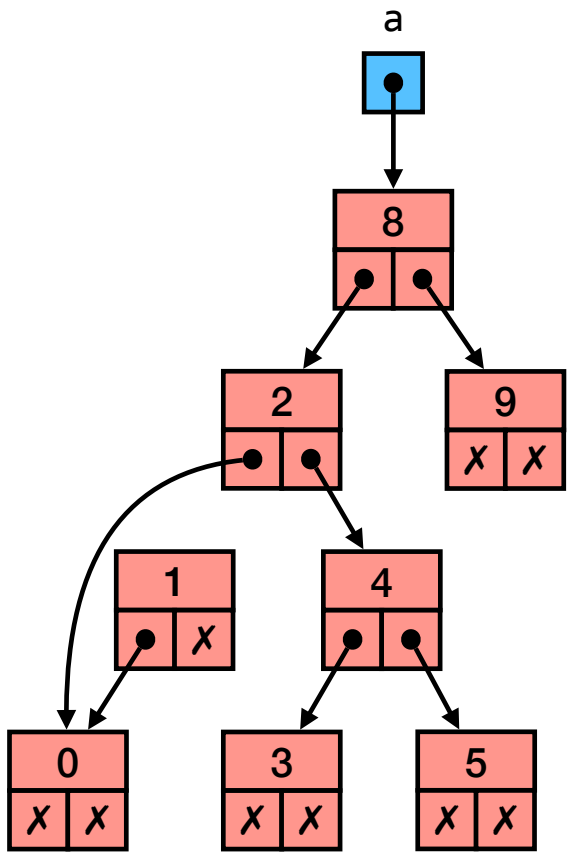
Remoção ordenada

```
int main() {
  abin a = …;
  a = delete(1, a);
  return 0;
}
```



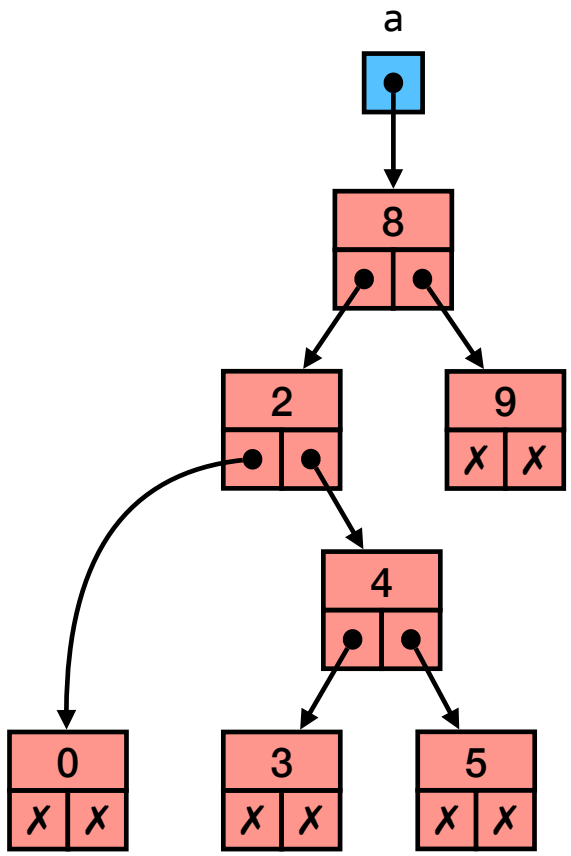
Remoção ordenada

```
int main() {
  abin a = …;
  a = delete(1, a);
  return 0;
}
```



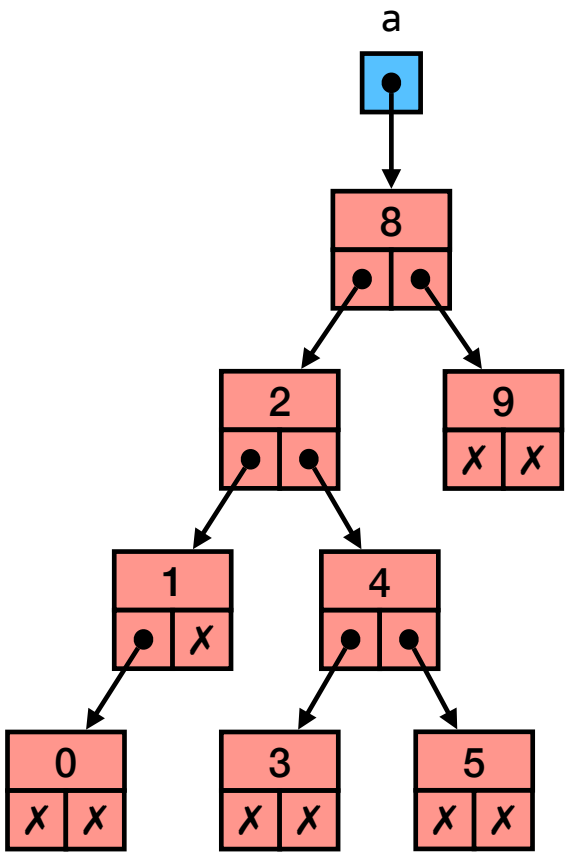
Remoção ordenada

```
int main() {
  abin a = …;
  a = delete(1, a);
  return 0;
}
```



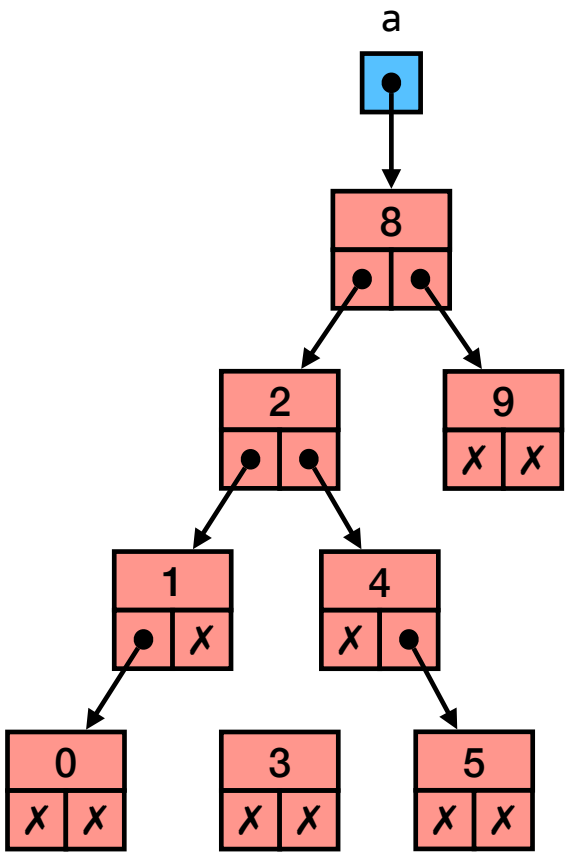
Remoção ordenada

```
int main() {
  abin a = …;
  a = delete(2, a);
  return 0;
}
```



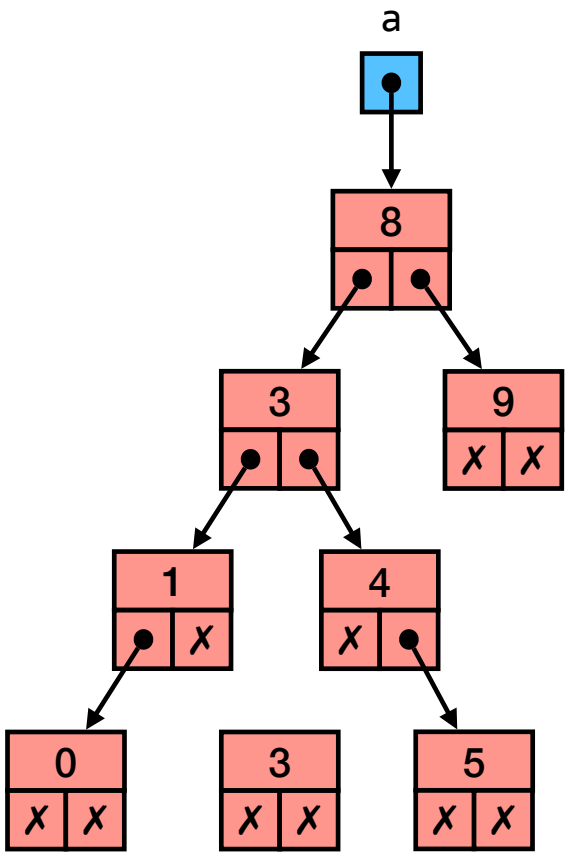
Remoção ordenada

```
int main() {
  abin a = …;
  a = delete(2, a);
  return 0;
}
```



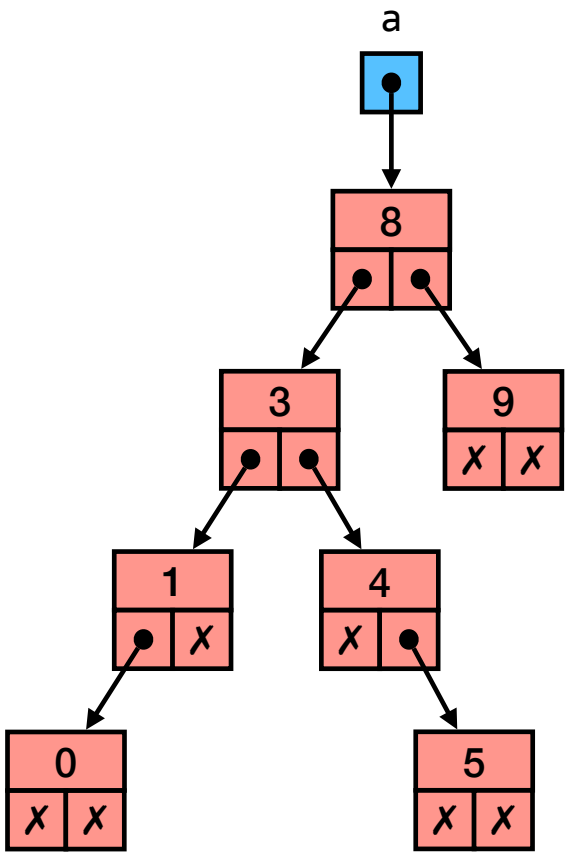
Remoção ordenada

```
int main() {
  abin a = …;
  a = delete(2, a);
  return 0;
}
```



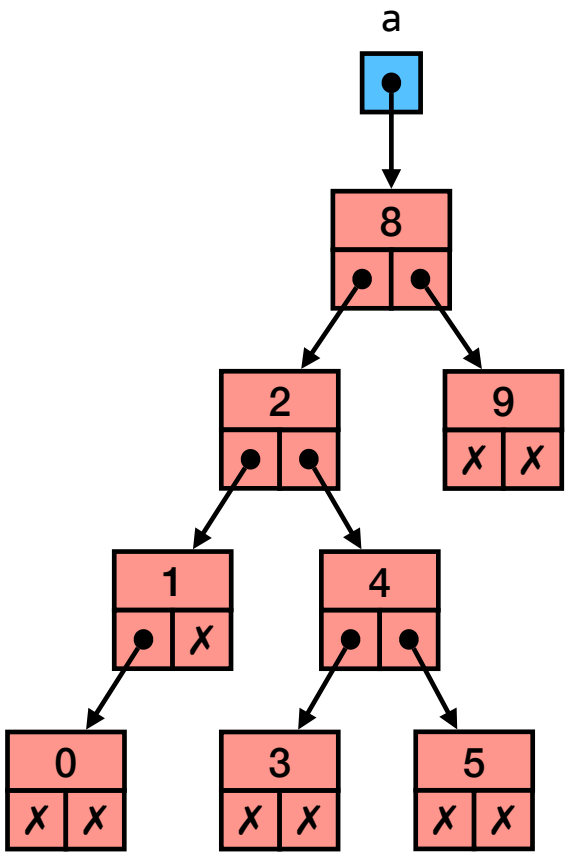
Remoção ordenada

```
int main() {
  abin a = …;
  a = delete(2, a);
  return 0;
}
```



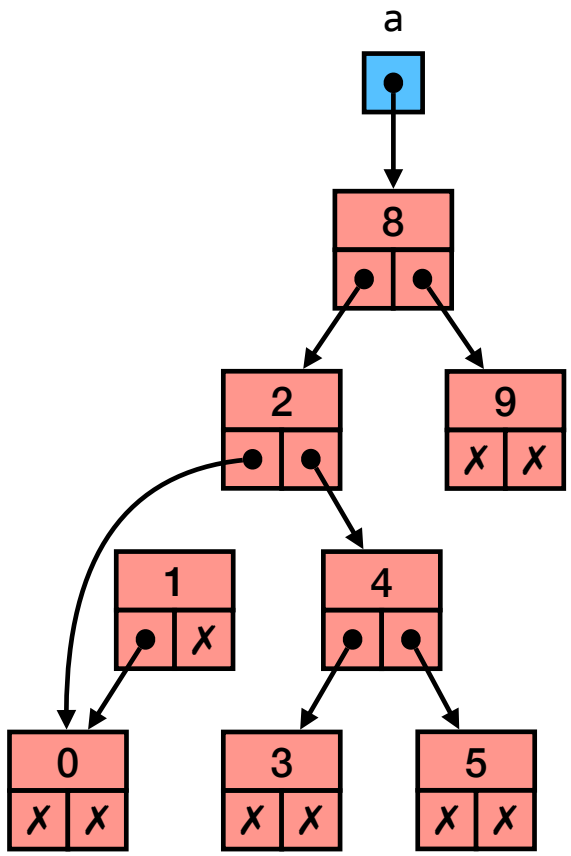
Remoção ordenada

```
int main() {
  abin a = …;
  a = delete(2, a);
  return 0;
}
```



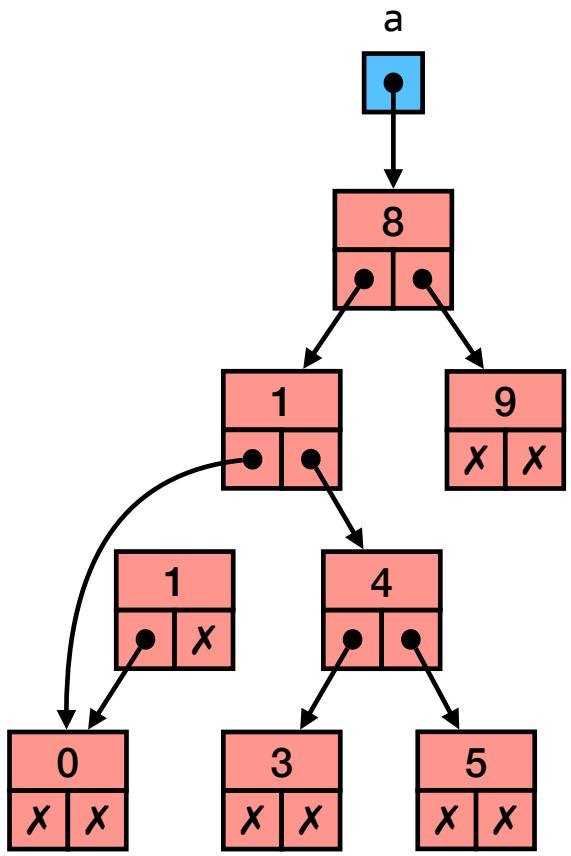
Remoção ordenada

```
int main() {
  abin a = …;
  a = delete(2, a);
  return 0;
}
```



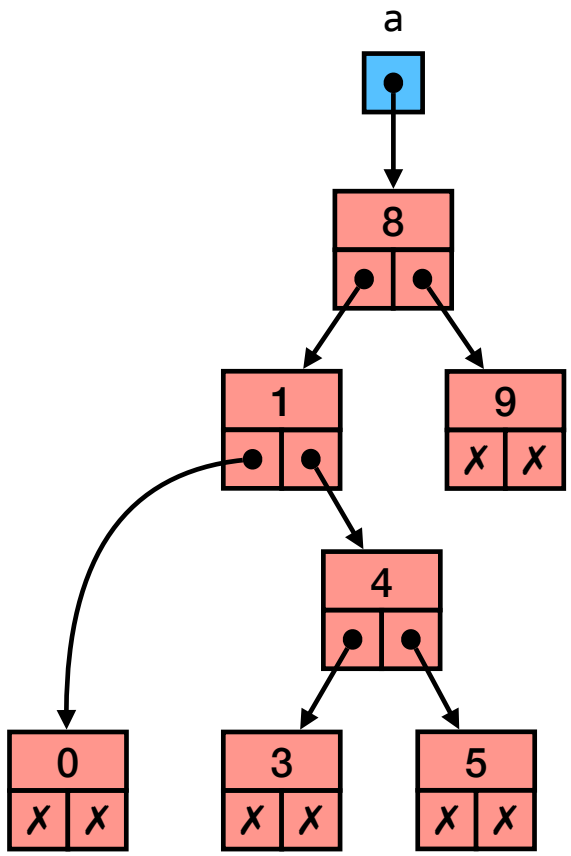
Remoção ordenada

```
int main() {
  abin a = …;
  a = delete(2, a);
  return 0;
}
```

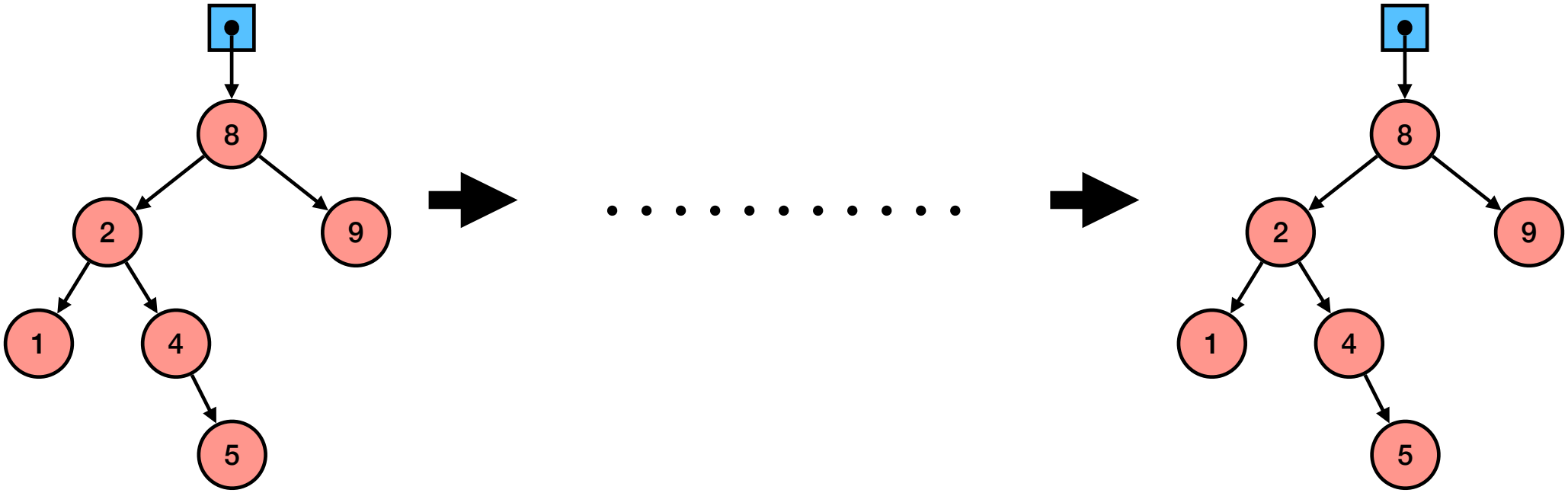


Remoção ordenada

```
int main() {
  abin a = …;
  a = delete(2, a);
  return 0;
}
```



Serializar árvore de procura

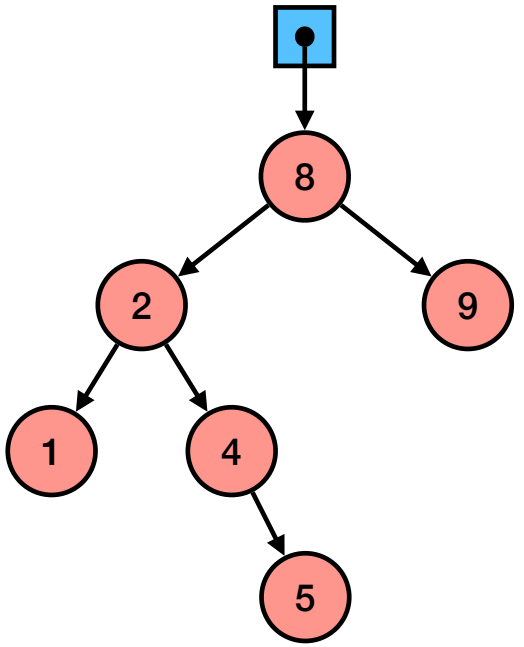


#31 Que travessias podem ser invertidas?

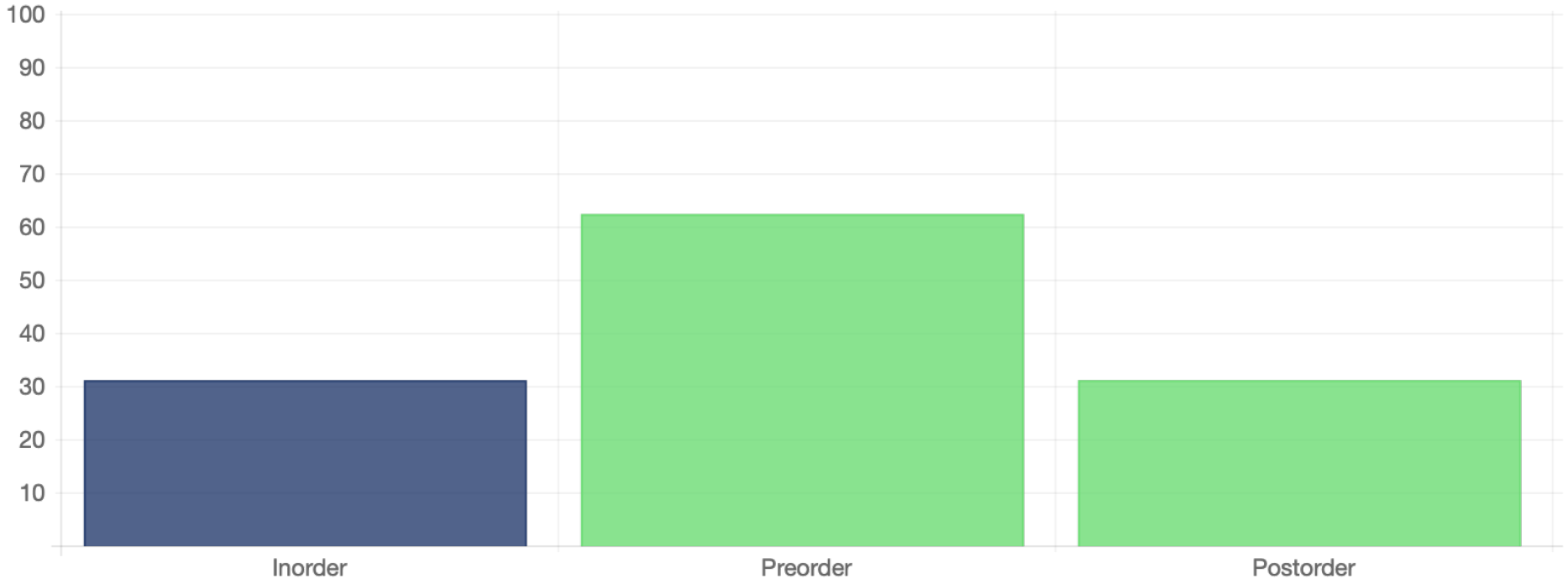
```
int toArrayInorder(abin a, int v[]);

int toArrayPreorder(abin a, int v[]);

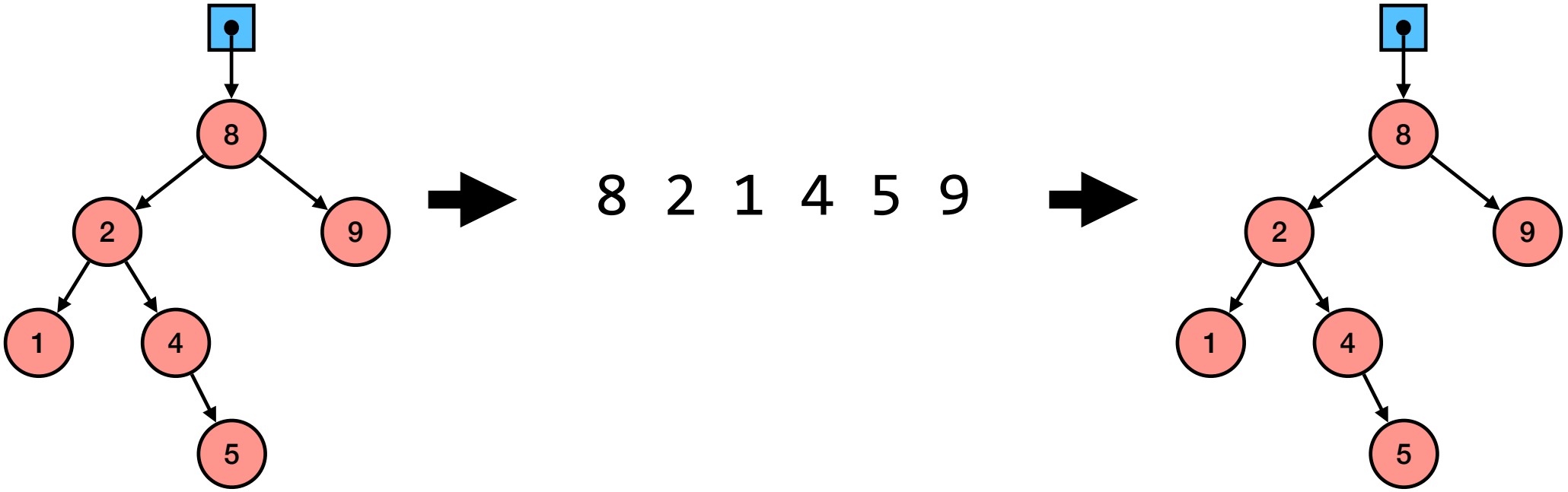
int toArrayPostorder(abin a, int v[]);
```



#31 Que travessias podem ser invertidas?



Serializar árvore de procura



Inverter array preorder

```
int aux(abin *a, int *max, int v[], int N) {
    abin l, r; int nl, nr;
    if (N == 0 || (max != NULL && v[0] > *max)) {
        *a = NULL;
        return 0;
    }
    nl = aux(&l, v, v+1, N-1);
    nr = aux(&r, NULL, v+nl+1, N-nl-1);
    *a = mkroot(v[0], l, r);
    return 1+nl+nr;
}

abin fromArrayPreorder(int v[], int N) {
    abin a;
    aux(&a,NULL,v,N);
    return a;
}
```

Serializar árvore arbitrária