C in a Nutshell, Pointers and Basic Data Structures

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Credits:
Emmanuel Fleury

C in a Nutshell

Hello World

```
#include <stdio.h>


int main(int argc, char *argv[])
{

  printf(“Hello world!\n”);



  return 0;
}
```

Hello World

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

include header for the definition of printf

```
int main(int argc, char *argv[])
{

  printf(“Hello world!\n”);



  return 0;
}
```

Hello World

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#include <stdio.h>

int main(int argc, char *argv[])
{
```

main->int ; argc: #arguments ; argv: arguments

```
  printf("Hello world!\n");

  return 0;
}
```

Hello World

```
#include <stdio.h>


int main(int argc, char *argv[])
{

  printf("Hello world!\n");



  return 0;
}
```

array of ***pointers*** to char
= array of strings

Hello World

```c
#include <stdio.h>


int main(int argc, char *argv[])
{
  printf("Hello world!\n");
  return 0;
}
```

printf function, argument = string
= char array terminated by 0

Hello World

```
#include <stdio.h>


int main(int argc, char *argv[])
{
  printf("Hello world!\n");
  return 0;
}
```

printf function, argument = string
= char array terminated by 0

string length given by
int strlen(char *)
declared in **string.h**

Hello World

```
#include <stdio.h>


int main(int argc, char *argv[])
{

  printf("Hello world!\n");



  return 0;
}
```

end of program, return to caller program

Syntax Reminder

- **if** statements:

  ```
  if (cond) statement else statement
  if (cond) { statements } else { statements }
  ```

  Advice: use { ... }

- **for** loops:

  ```
  for(statements;cond; progress) { statements }
  ```

  Advice: use { ... }

- **while** loops/**do** - **while** loops:

  ```
  while(cond) { statements }
  do { statements } while(cond);
  ```

  Advice: use { ... }

Types

- Scalars:
  `int, char, short, long,`
  `float, double,`
  `unsigned int, unsigned char,..`

- Records:
  `struct` *`name`* `{` *`types`* `};`

- Type definitions:
  `typedef` *`some_type my_type`*`;`

Types: Examples

Custom type for unsigned integers:

```
typedef unsigned int uint;
```

Custom type for a pair of unsigned integers:

```
typedef struct { uint first, second; } pair_t;
```

Using your pair:

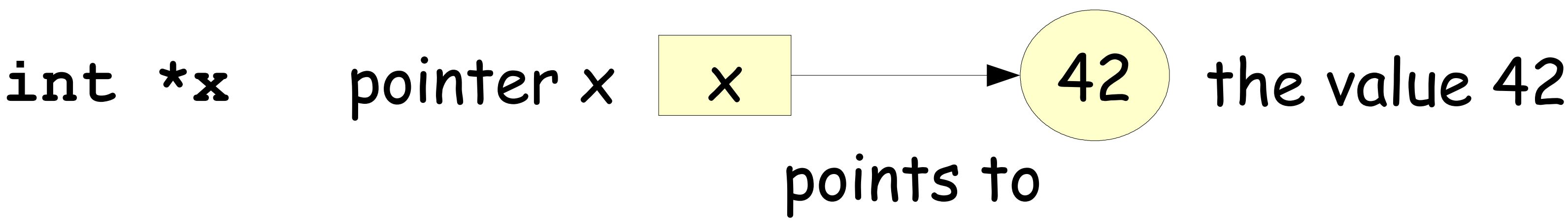
```
pair_t p;
p.first = 0;
p.second = 1;
```

Similar to Java: a struct is like a class with public fields and without method.

Pointers in a Nutshell

Pointers in a Nutshell

- Pointers and “Pointees”: a pointers stores a reference to something.



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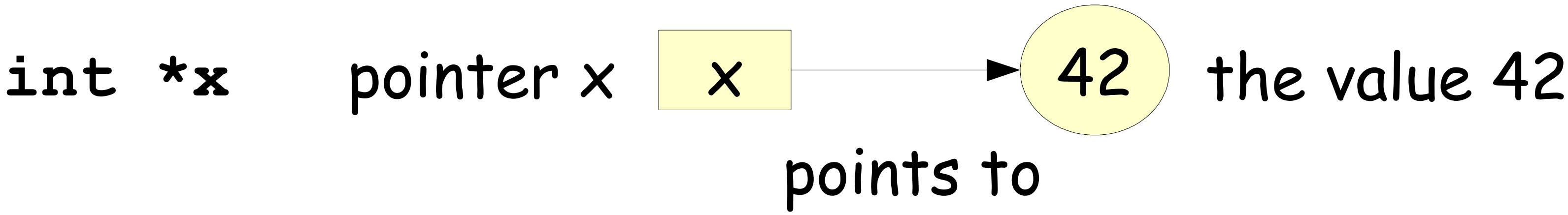
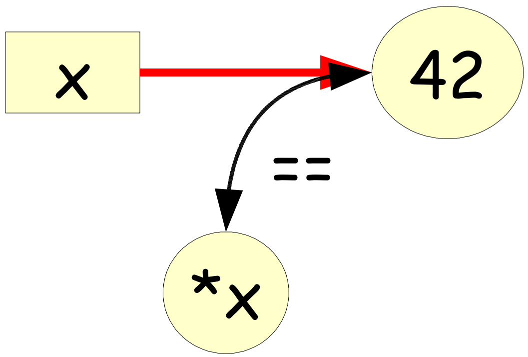
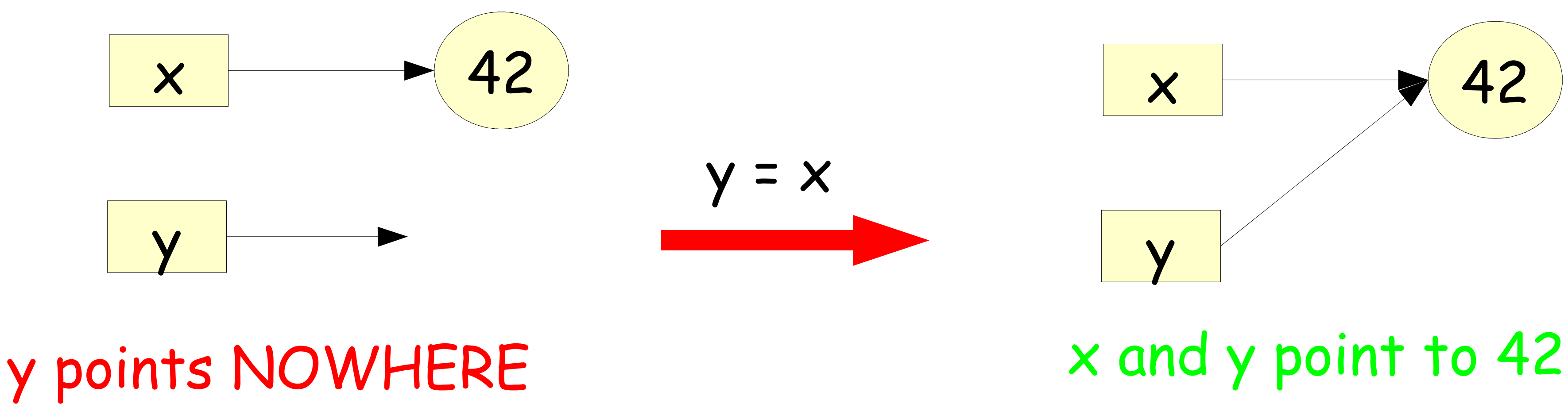


- Dereference operation: starts from the pointer and follows its arrow to access its content ("pointee").



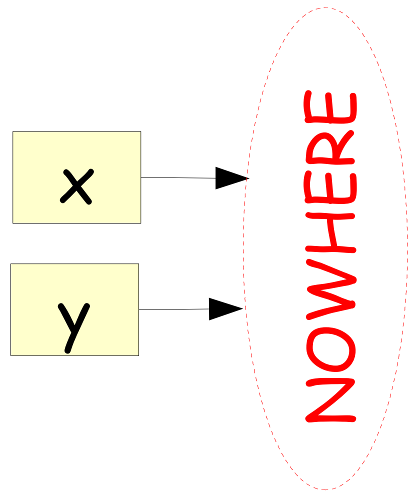
Pointers in a Nutshell

- Pointer assignment between 2 pointers makes them point to the same thing.
- The "pointee" becomes ***shared*** between the 2 pointers.



Binky's Code Example

```
int *x, *y;
```



Allocate 2 pointers. **This does not allocate the pointee.**

Binky's Code Example

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int *x, *y;
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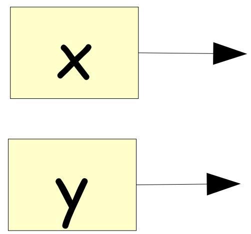
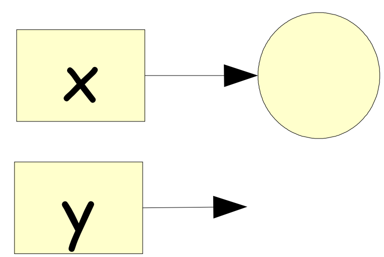


Allocate 2 pointers. **This does not allocate the pointee.**

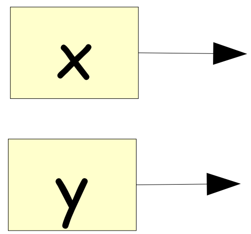
```
x = (int*) malloc(sizeof(int))
```



Allocate a pointee and set x to point to it.

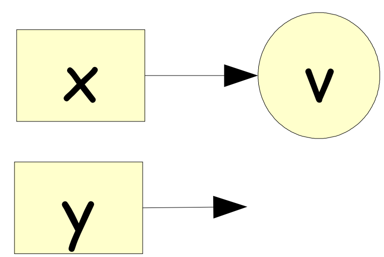
Binky's Code Example

```
int *x, *y;
```



Allocate 2 pointers. **This does not allocate the pointee.**

```
int v;
x = &v;
```



Allocate a pointee and set x to point to it.

Binky's Code Example

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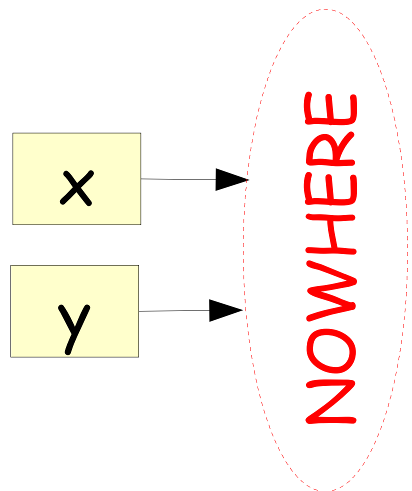

Allocate 2 pointers. **This does not allocate the pointee.**

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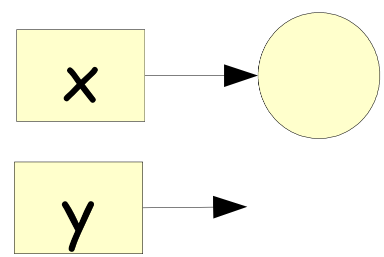
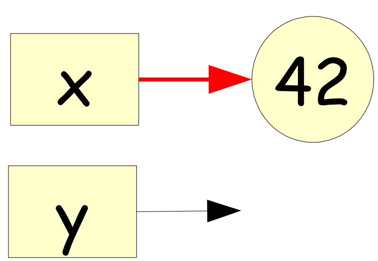


Allocate a pointee and set x to point to it.

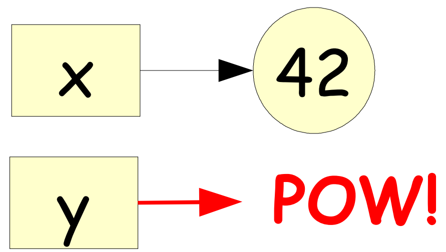
*x = 42



Dereference x to store 42 in its pointee.

Binky's Code Example

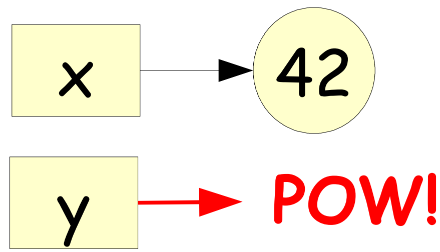
*y = 13



Try to dereference y by storing 13 in its pointee: **there is no pointee!**

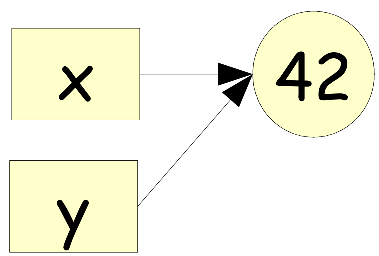
Binky's Code Example

*y = 13



Try to dereference y by storing 13 in its pointee: **there is no pointee!**

y = x



Assign y to x. Now the pointers share the same pointee.

Binky's Code Example

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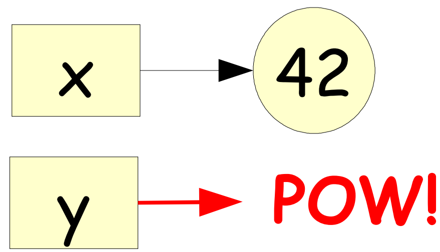

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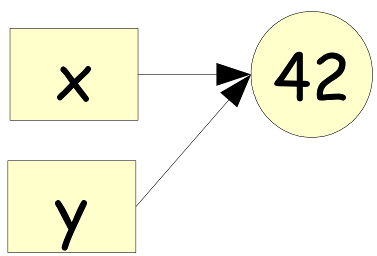

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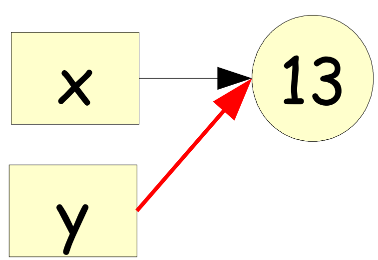
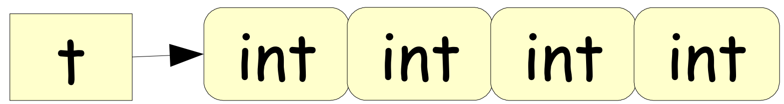
*y = 13



Dereference y and store 13 in its pointee. Note: *x would return 13 now.

More Pointer Fun!

```
int table[4];
int *t = table;
```



int * : points to one or more ints (table of ints).

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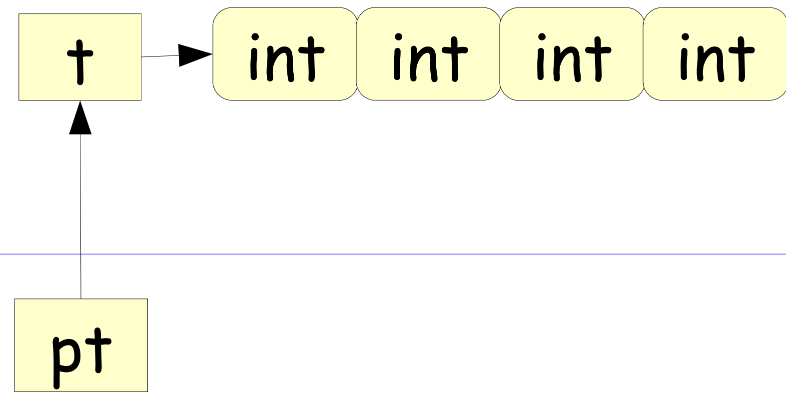

int * : points to one or more ints (table of ints).

int **pt = &t;

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int * : points to one or more ints (table of ints).

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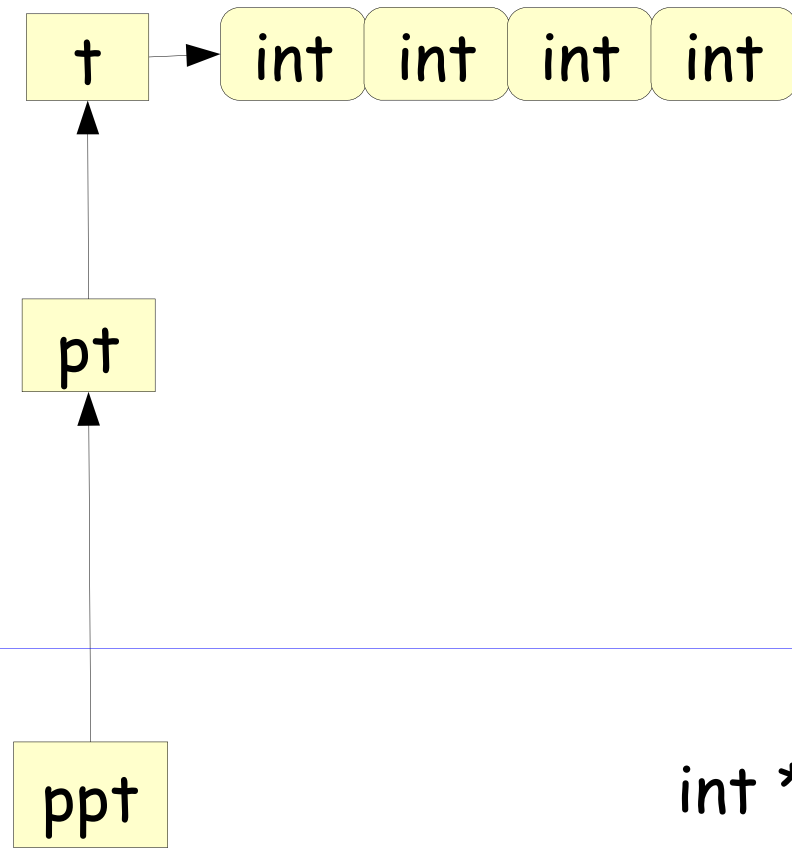
int **pt = &t;
```

int ** : points to one or more int* (table of int*).

```
int ***ppt = &pt;
```

int *** : ... you get it now!



Pointers: Example

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


...
int a = 1;
int b = 2;
...
swap(&a, &b);
...
```

a=1

Pointers: Example

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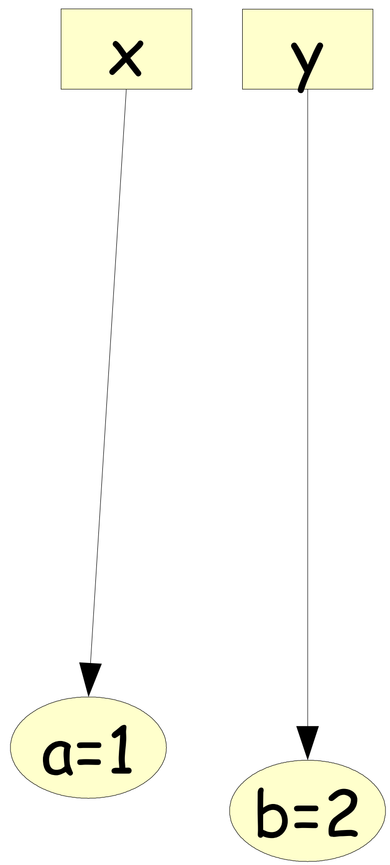

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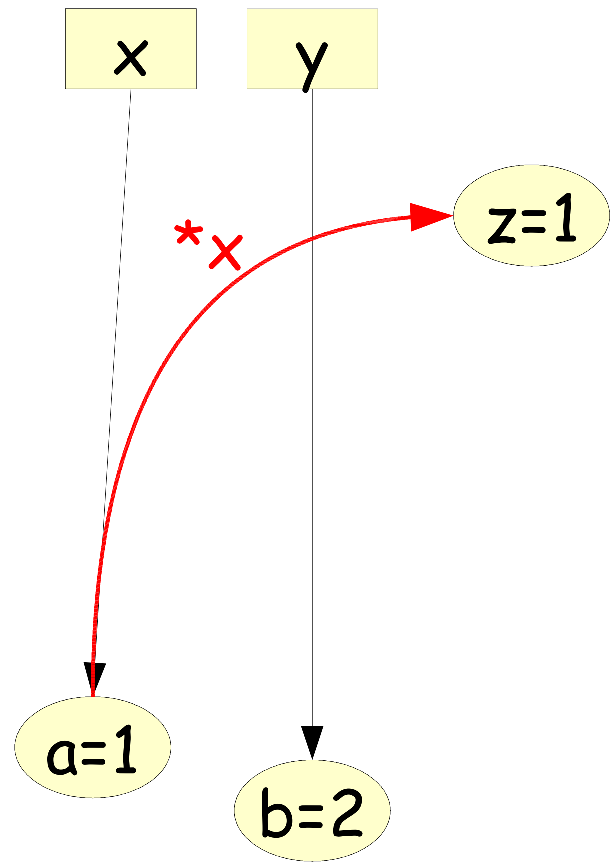

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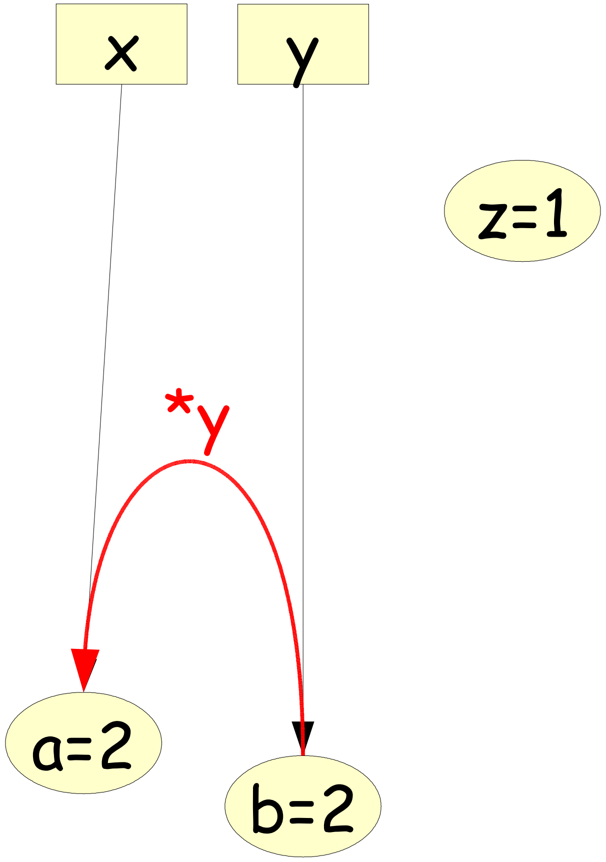

Pointers: Example

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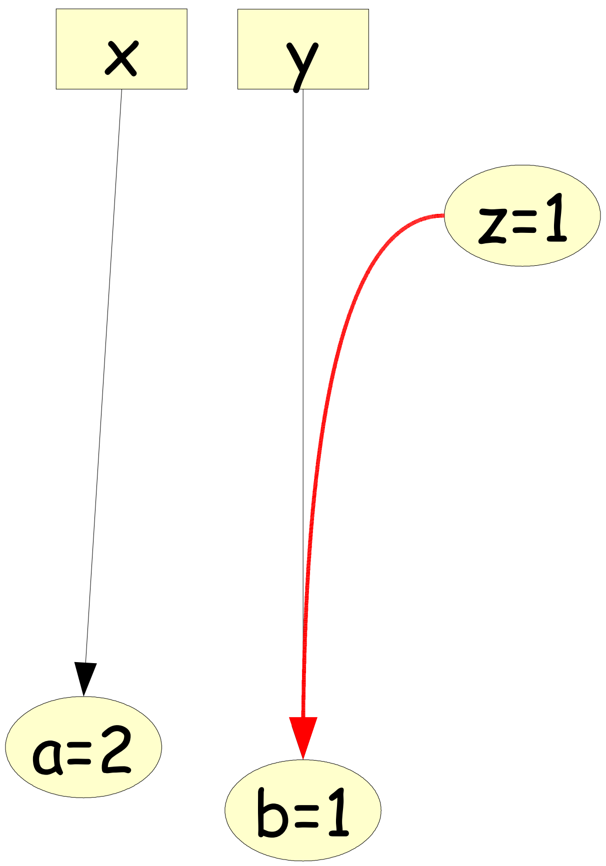

Pointer Arithmetics

- Addition: **pointer + index -> pointer**

  int *p; "p+3" same as "&p[3]" -> int*

- Subtraction: **pointer – pointer -> index**

  int a[4], *p = &a[1], *q = &a[3];

  "q-p" == 2 -> int

Pointer Arithmetics

- Addition: **pointer + index -> pointer**
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- Subtraction: **pointer - pointer -> index**
  int a[4], *p = &a[1], *q = &a[3];
  "q-p" == 2 -> int
- **Pointers are typed!**
  int *p; "p+1" points to next integer!
  char *c; "c+1" points to next character!

Big-O Notation in a Nutshell

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$$T(n) \in O(f(n))$$

means T(N) is upper bounded by f(n) (at a multiplicative constant) for n "big enough".

Big-O Notation in a Nutshell

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means T(N) is upper bounded by f(n) (at a multiplicative constant) for n "big enough".

Characterizes the way the complexity of the computation grows depending on the size of the problem.

Big-O Notation Example

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

Complexity: O(n)

Big-O Notation Summary

Notation	Name
$O(1)$	Constant
$O(\log n)$	Logarithmic
$O(n)$	Linear
$O(n.\log n)$	Pseudo-linear
$O(n^2)$	Quadratic
$O(n^3)$	Cubic
$O(n^c)$	Polynomial
$O(c^n)$	Exponential
$O(n!)$	Factorial

Big-O Notation Summary

Notation	Name	
$O(1)$	Constant	Very Easy
$O(\log n)$	Logarithmic	
$O(n)$	Linear	Easy
$O(n.\log n)$	Pseudo-linear	
$O(n^2)$	Quadratic	Hard
$O(n^3)$	Cubic	
$O(n^c)$	Polynomial	
$O(c^n)$	Exponential	Very Hard
$O(n!)$	Factorial	

Elementary Data Structures

Choosing a Data Structure

Algorithms consume resources:

- Time (CPU Power)
- Space (Memory Space)

Choosing a data structure is a trade-off between time and space complexity:

- How fast can we access/modify the data ?
- How small can we code/compress the data ?
- ...

Common Operators

Basic Operators:

- search(set, key)
- insert(set, key)
- delete(set, element)

Other Operators:

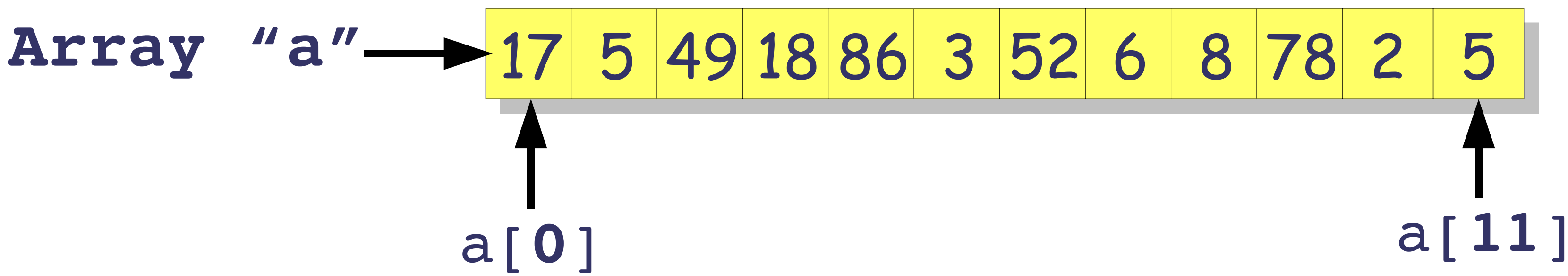
- sort(set)
- min(set), max(set)
- succ(set,elt), pred(set,elt)
- empty(set), count(set)

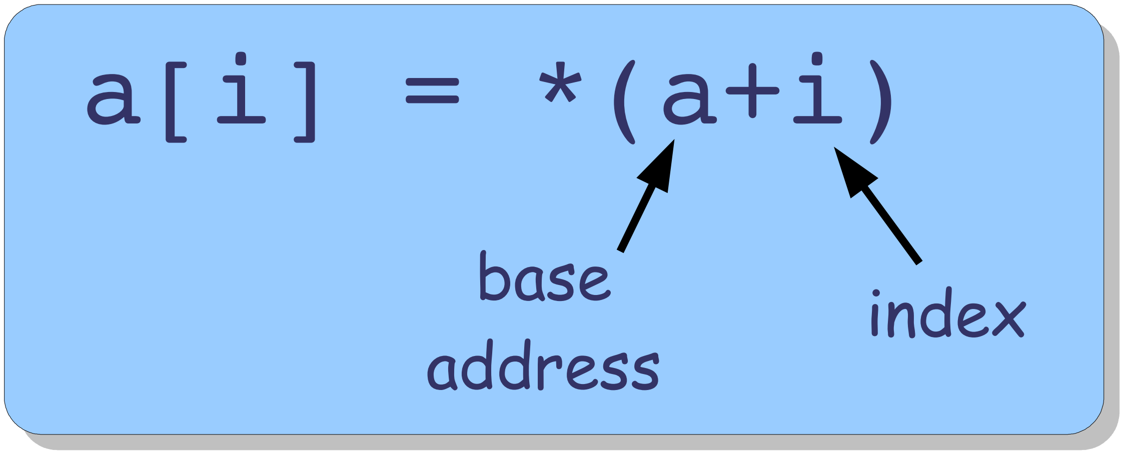
Choose your data-structure depending on what operations will be performed the most !

Arrays

One-dimension Arrays

Declaration: `int a[12];`

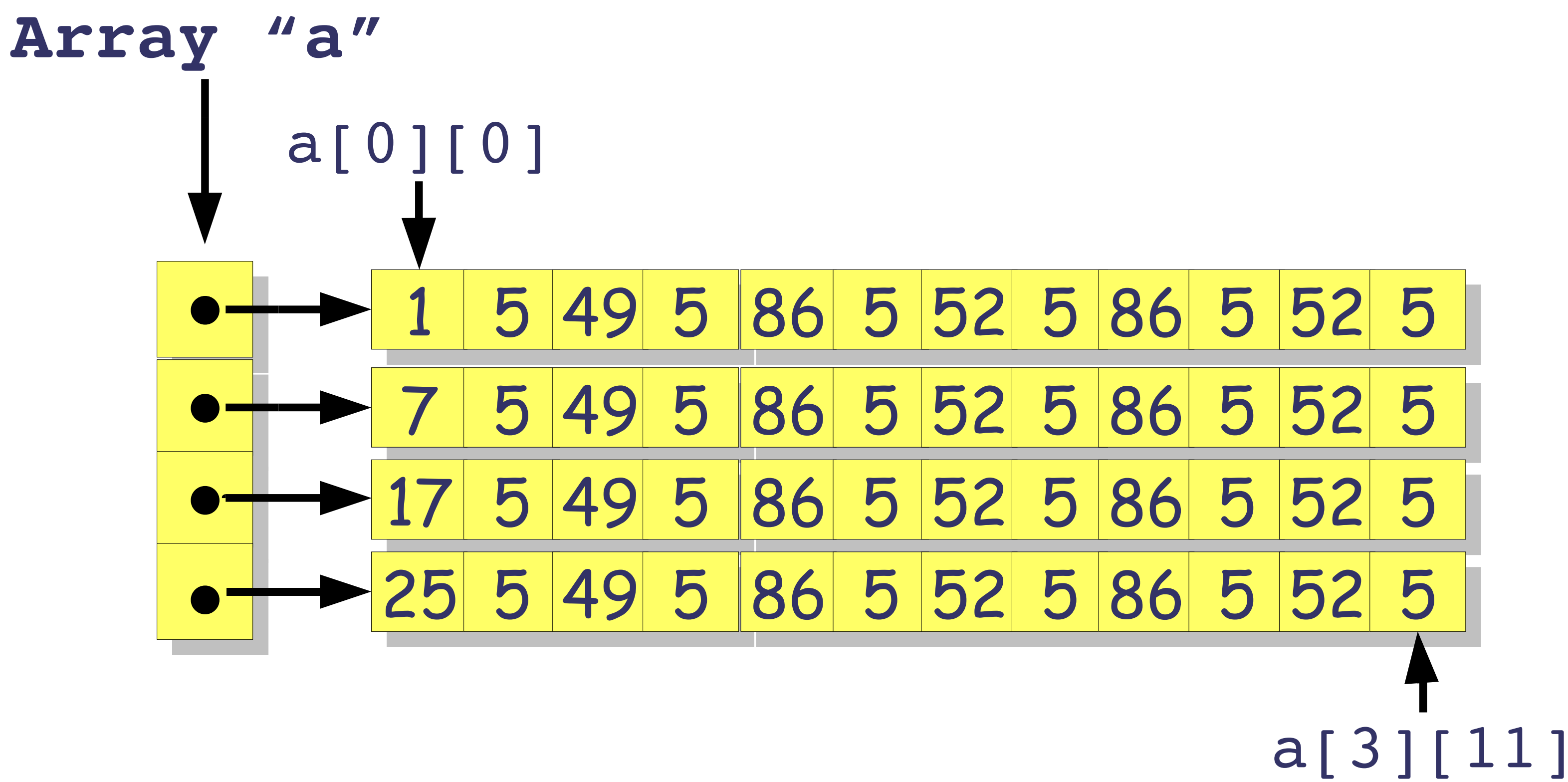




Two-dimensions Arrays

Declaration:

```
int a[4][12];
```




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

Complexity (Arrays)

Operator	Time	Space
search(set, key)	O(1)	O(1)
insert(set, key)	O(n)	O(n)
delete(set, key)	O(n)	O(n)
min(set) / max(set)	O(n)	O(1)
succ(set,elt)/pred(set,etl)	O(n)	O(1)
isempty(set)	O(1)	O(1)
count(set)	O(1)	O(1)

n is the number of elements in the array

key is the index of an element

Matrix Copy

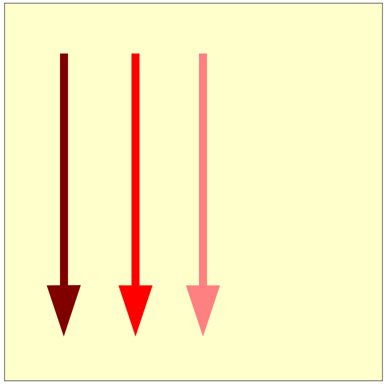
(why locality is good...)

copy1

```
int copy1(float src[SIZE_X][SIZE_Y],
          float dest[SIZE_X][SIZE_Y]) {
  int i, j;

  for (j=0; j<SIZE_Y; j++)
    for (i=0; i<SIZE_X; i++)
      dest[i][j] = src[i][j];

  return 0;
}
```



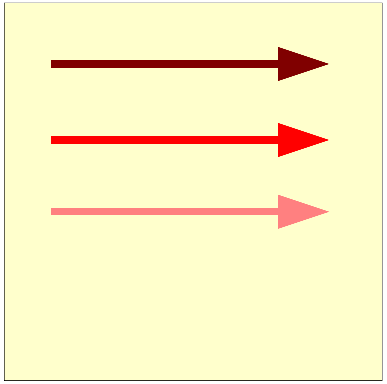
#define SIZE_X 20
#define SIZE_Y 20

copy2

```
int copy2(float src[SIZE_X][SIZE_Y],
          float dest[SIZE_X][SIZE_Y]) {
  int i, j;

  for (i=0; i<SIZE_X; i++)
    for (j=0; j<SIZE_Y; j++)
      dest[i][j] = src[i][j];

  return 0;
}
```

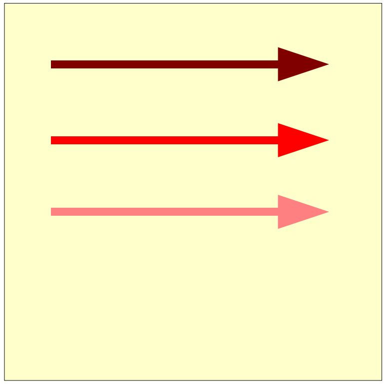


copy3

```
int copy3(float* src, float* dest) {
  int size;

  for (size=(SIZE_X*SIZE_Y); size; size--)
    *dest++ = *src++;

  return 0;
}
```



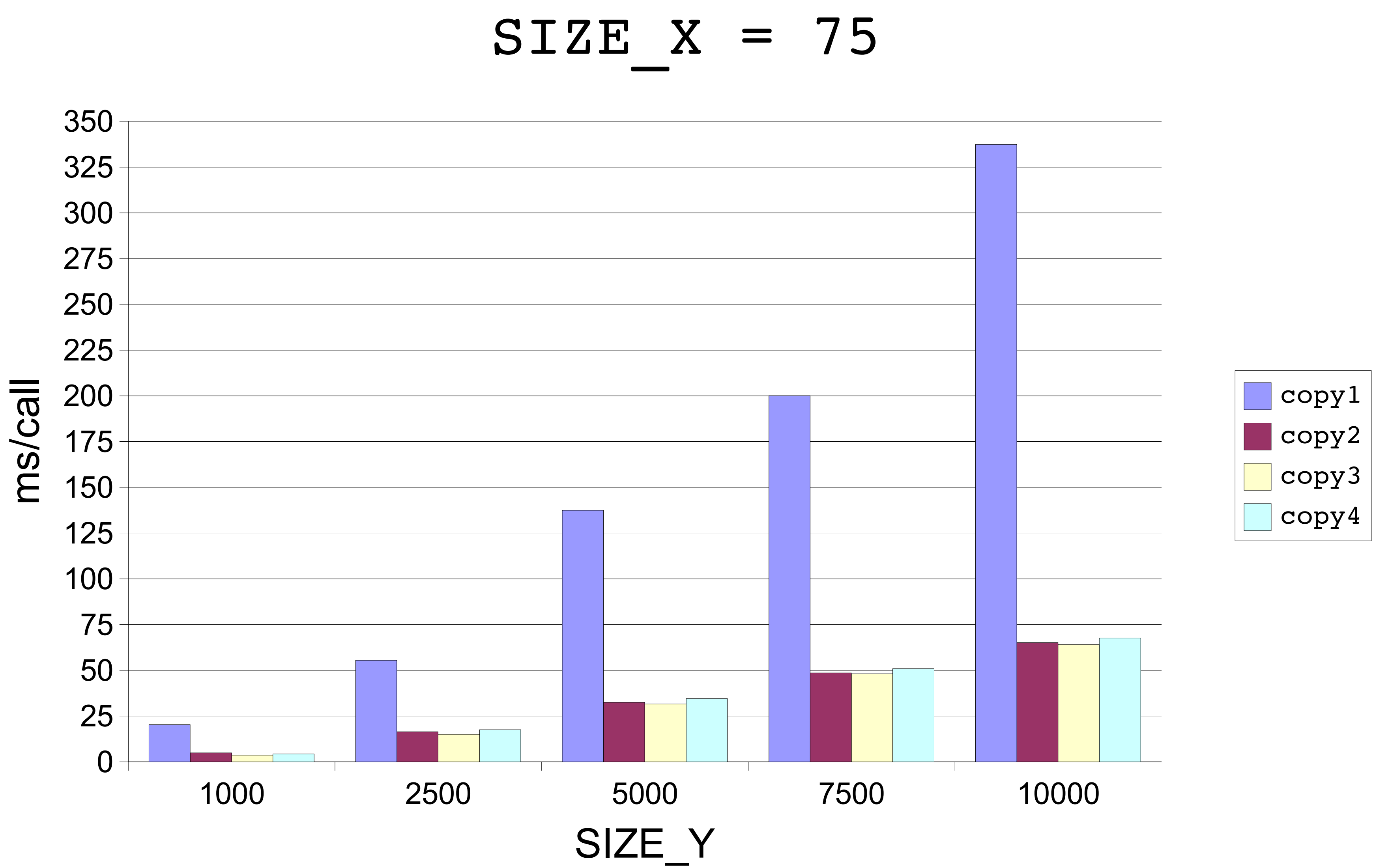
copy4

```
int copy4(float* src, float* dest) {

  memcpy(dest, src,
          (SIZE_X*SIZE_Y)*sizeof(float));

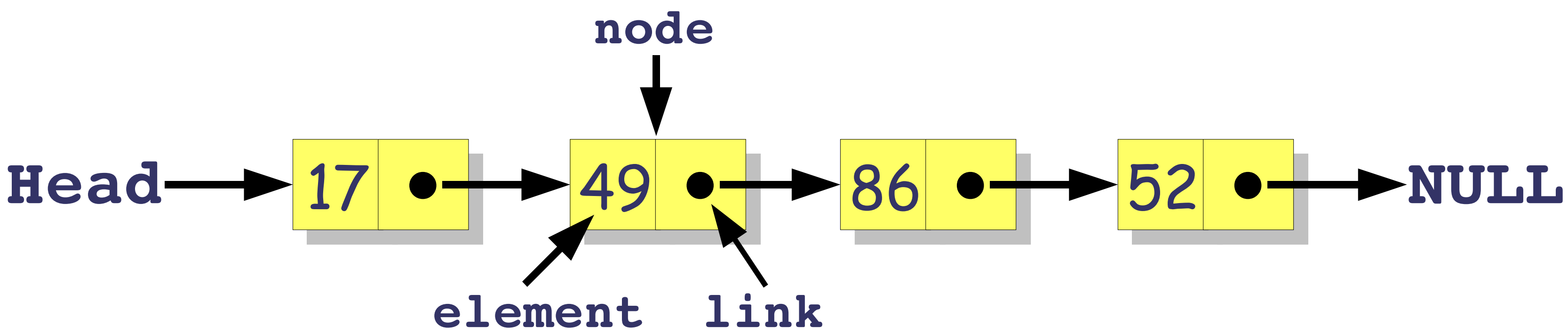
  return 0;
}
```

Performance



Linked-lists

Singly Linked-lists

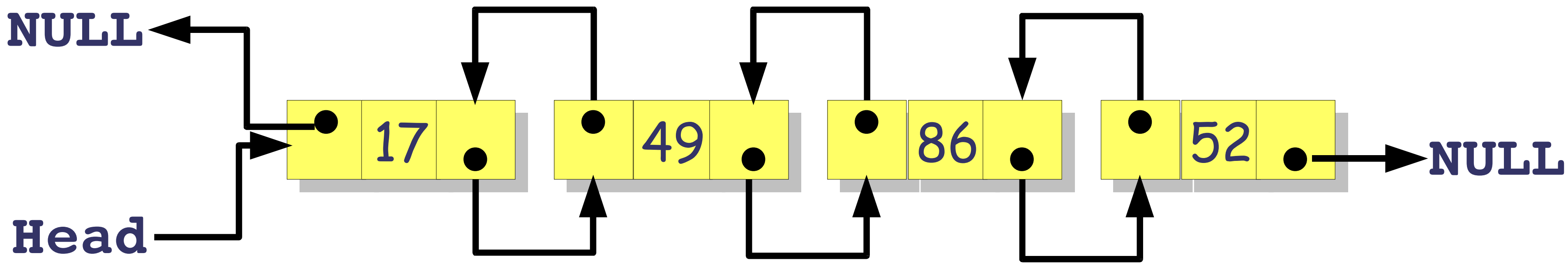


Declaration:

```
struct list {
  int value;
  struct list* next;
};
```

Memory Overhead: One extra pointer for each element

Doubly Linked-lists



Declaration:

```
struct list {
  struct list* pred;
  int value;
  struct list* next;
};
```

Memory Overhead: Two extra pointers for each element

Search

Requirements:

- Return a pointer to the right node
- Return NULL if not found

```
struct list* search(struct list *head,
                    const int key)
```

Search

```
struct list* search(struct list *head,
                    const int key) {

  while ((head != NULL)&&(head->value != key))
    head = head->next;

  return head;
}
```

Insert

Requirements:

- Return a pointer to the inserted node
- Return NULL in case the malloc fail
- Can handle the case where the list is NULL

```
struct list* insert(struct list *head,
                    const int value)
```

Insert

```
struct list* insert(struct list *head, const int value) {
  struct list *tmp, *new;

  new = (struct list*) malloc(sizeof(struct list));

  if (new != NULL) {
    new->value = value;
    new->next = head;
  }

  return new;
}
```

also fine if head is null

Delete

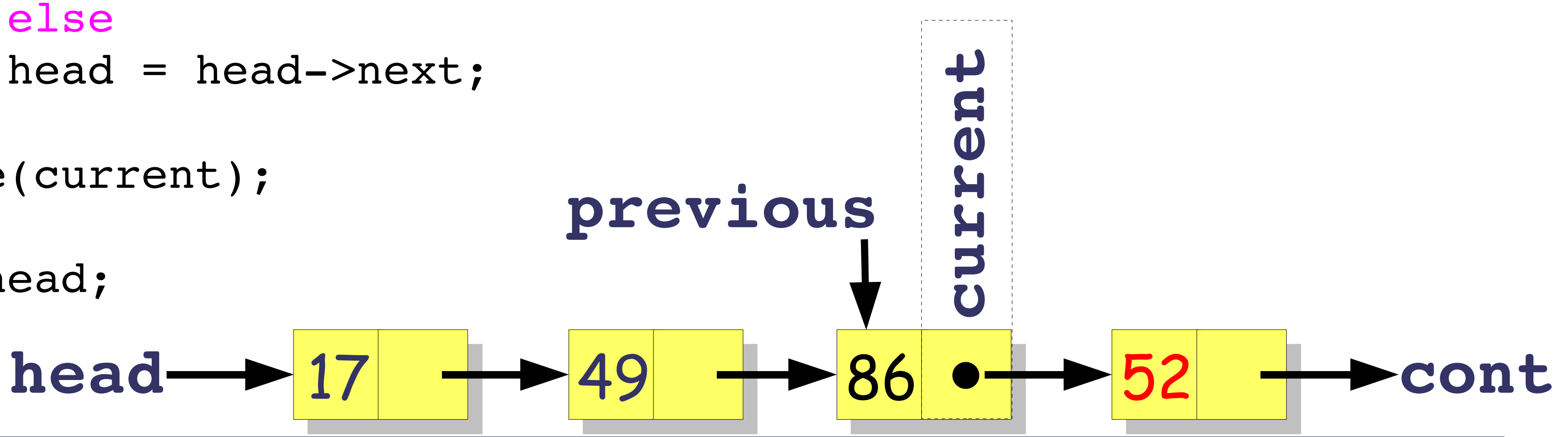
Requirements:

- Return a pointer to the head node
- Return NULL when deleting a singleton list
- Can handle the case where the list is NULL

```
struct list* delete(struct list *head,
                    const int value)
```

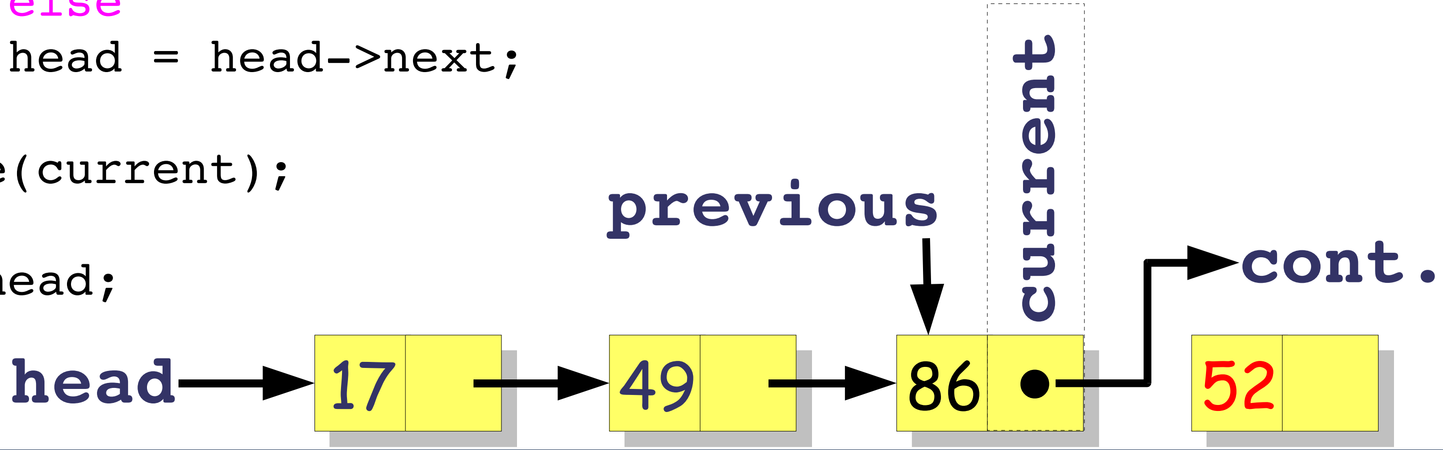
Delete

```c
struct list* delete(struct list *head, const int value) {
  struct list *current = head, *previous = head;

  if (head != NULL) {
      if (head->value != value) {
          current = current->next;

          while ((current != NULL) && (current->value != value)) {
            previous = current;
            current = current->next;
          }
          if (current != NULL)
            previous->next = current->next;
        } else
          head = head->next;

      free(current);
    }
  return head;
}
```



Delete

```
struct list* delete(struct list *head, const int value) {
  struct list *current = head, *previous = head;

  if (head != NULL) {
      if (head->value != value) {
          current = current->next;

          while ((current != NULL) && (current->value != value)) {
            previous = current;
            current = current->next;
          }
          if (current != NULL)
            previous->next = current->next;
        } else
          head = head->next;

      free(current);
    }
  return head;
}
```



Complexity (Linked-lists)

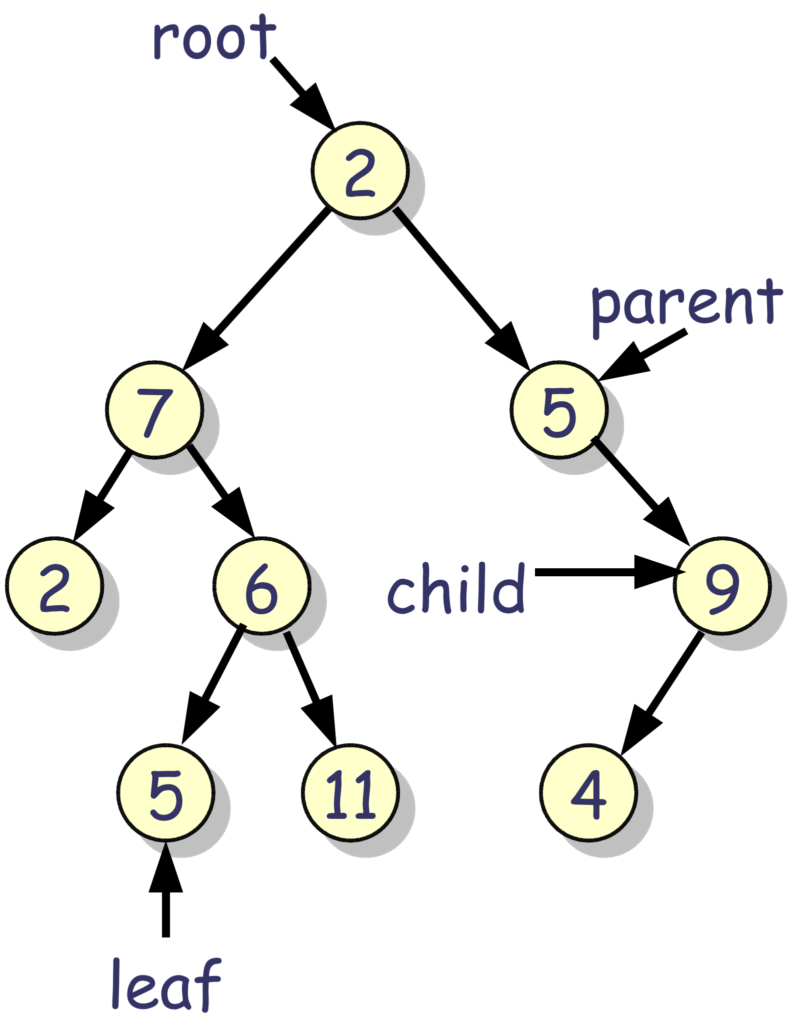
Operator	Time	Space
search(set, key)	O(n)	O(1)
insert(set, key)	O(1)	O(1)
delete(set, key)	O(n)	O(1)
min(set) / max(set)	O(n)	O(1)
succ(set,elt)/pred(set,etl)	O(n)	O(1)
isempty(set)	O(1)	O(1)
count(set)	O(n)	O(1)

n is the number of elements in the linked-list

key is a value

Trees

Trees



Definitions:

- Each node has zero or more children
- A node with a child is a parent
- A node without a child is a leaf
- A node without a parent is a root

```
struct tree {
  int value;
  struct tree *left;
  struct tree *right;
};
```

Pre-order

```
void traverse(struct tree *node) {

  printf("Value is: %i\n", node->value);

  if (node->left != NULL)
    traverse(node->left);

  if (node->right != NULL)
    traverse(node->right);

  return;
}
```

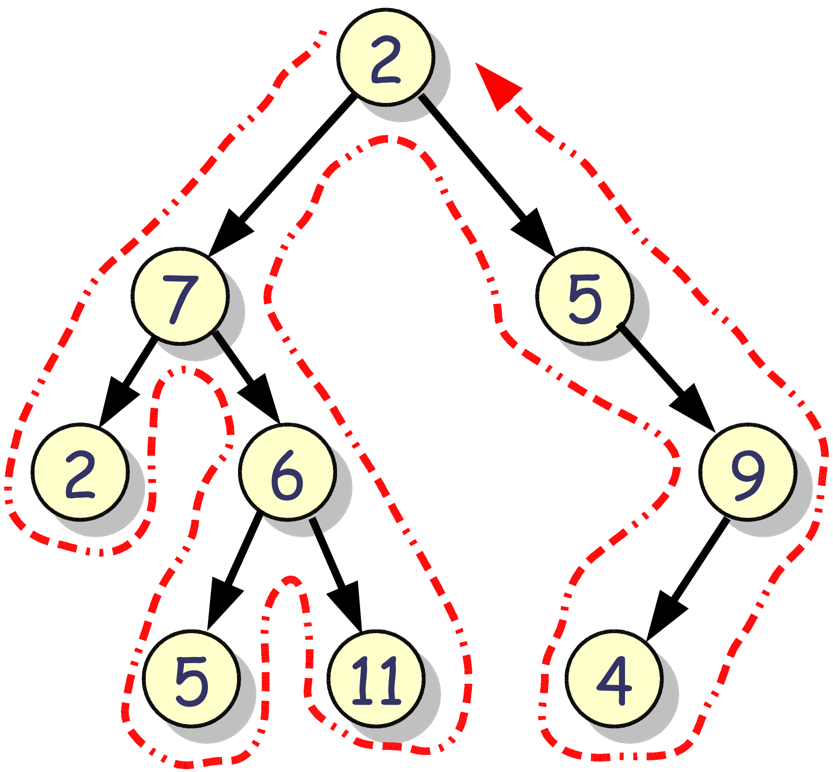
In-order

```
void traverse(struct tree *node) {

  if (node->left != NULL)
    traverse(node->left);

  printf("Value is: %i\n", node->value);

  if (node->right != NULL)
    traverse(node->right);

  return;
}
```

Post-order

```c
void traverse(struct tree *node) {

  if (node->left != NULL)
    traverse(node->left);

  if (node->right != NULL)
    traverse(node->right);

  printf("Value is: %i\n", node->value);

  return;
}
```

Tree Traversal



- Pre-order:
  2, 7, 2, 6, 5, 11, 5, 9, 4
- Post-order:
  2, 5, 11, 6, 7, 4, 9, 5, 2
- In-order:
  2, 7, 5, 6, 11, 2, 5, 4, 9

Operators on Trees

- Breadth-first Operators:

  The operation on the node is applied <u>before</u> exploring the children

- Depth-first Operators:

  The operation on the node is applied <u>after</u> exploring the children

Complexity (Trees)

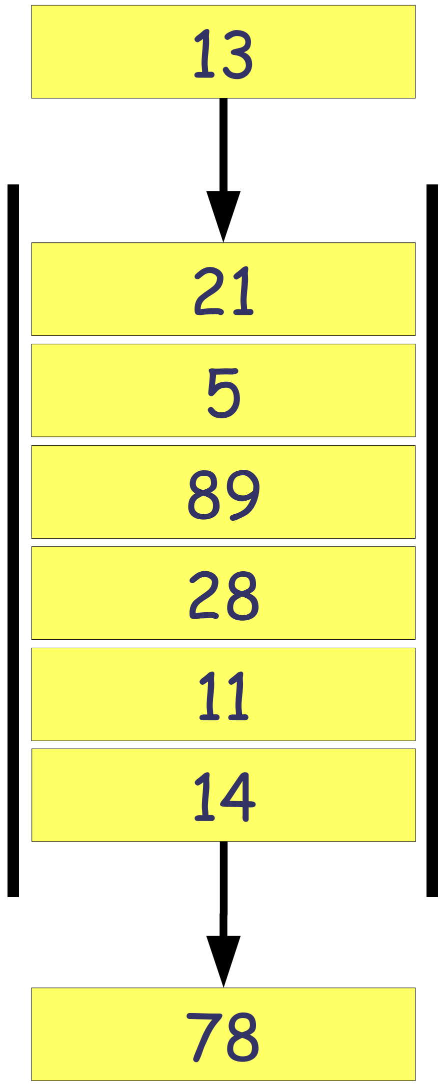
Operator	Time	Space
search(set, key)	O(n)	O(1)
insert(set, key)	O(n)	O(1)
delete(set, key)	O(n)	O(1)
min(set) / max(set)	O(n)	O(1)
succ(set,elt)/pred(set,etl)	O(n)	O(1)
isempty(set)	O(1)	O(1)
count(set)	O(n)	O(1)

<u>n</u> is the number of elements in the tree

Some Usual Data Structures

Queues
(FIFO)

Queues (FIFO)



First In First Out

- Implemented via:
  - Array
  - Linked-list
- Applications:
  - Buffers and Spoolers (networks, printer, scheduler, ...)

Complexity (Queues)

Operator	Time	Space
search(set, key)	O(n)	O(n)
insert(set, key)	O(1)	O(1)
delete(set, key)	O(n)	O(n)
min(set) / max(set)	O(n)	O(n)
succ(set,elt)/pred(set,etl)	O(n)	O(n)
isempty(set)	O(1)	O(1)
count(set)	O(n)	O(n)

n is the number of elements in the queue

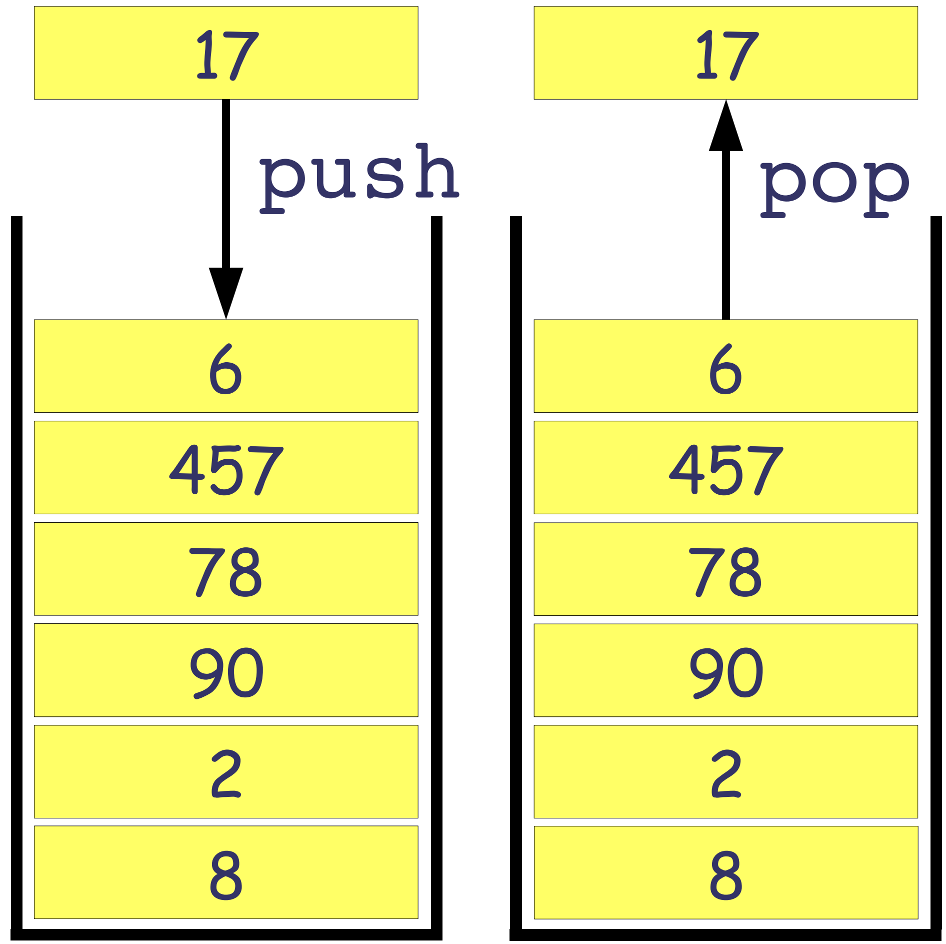
key is a value

Stacks
(FILO)

Stacks (FILO)

First In Last Out

- Implemented via:
  - Array
  - Linked-list
- Applications:
  - Stack based calculus (CPU, parser, ...)



Complexity (Stacks)

Operator	Time	Space
search(set, key)	O(n)	O(n)
insert(set, key)	O(1)	O(1)
delete(set, key)	O(n)	O(n)
min(set) / max(set)	O(n)	O(n)
succ(set,elt)/pred(set,etl)	O(n)	O(n)
isempty(set)	O(1)	O(1)
count(set)	O(n)	O(n)

n is the number of elements in the stack

key is a value

Binary Heaps

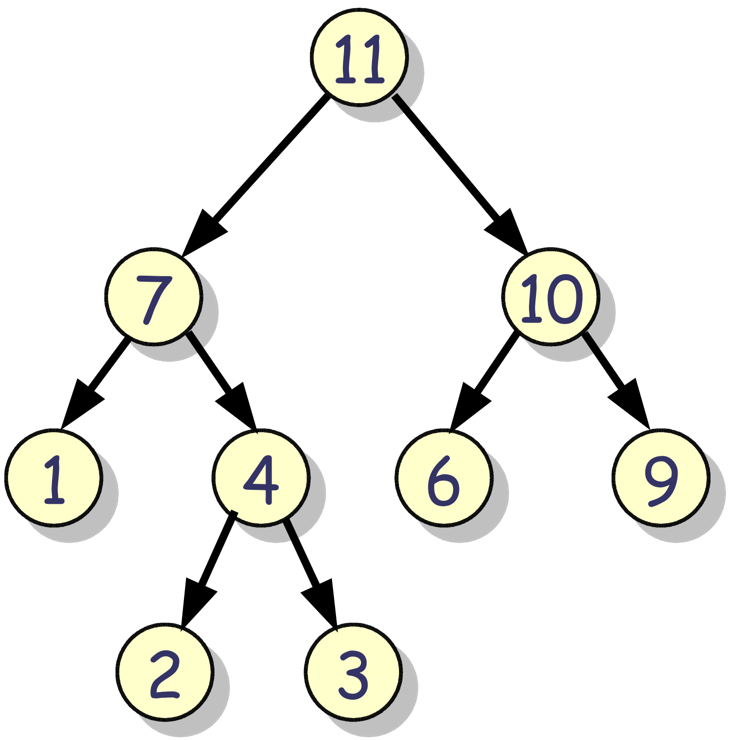
Binary Heaps

A heap is a tree structure such that, if A and B are nodes of a heap and B is a child of A, then:

$$key(A) \geq key(B)$$

A binary heap is a heap based on a binary tree

Binary Heaps



- Implemented via:
  - Array
    (a[i] has two children a[2i+1],a[2i+2])
  - Tree
- Applications:
  - Quick access to data
    (database, ...)

Complexity (Binary Heaps)

Operator	Time	Space
search(set, key)	O(log n)	O(1)
insert(set, key)	O(log n)	O(1)
delete(set, key)	O(log n)	O(1)
min(set) / max(set)	O(log n)	O(1)
succ(set,elt)/pred(set,etl)	O(log n)	O(1)
isempty(set)	O(1)	O(1)
count(set)	O(n)	O(1)

n is the number of elements in the heap

key is a value

Questions ?