Programming Paradigms

Composite Types (Part 3)

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Quiz

What does the following C code print?

```
char *cptr = (char *) 0x1000;
int *iptr = (int *) 0x1000;

void *a = cptr+4;
void *b = iptr+4;

printf("%p %p\n", a, b);
```

Please vote via Ilias.

Quiz

What does the following C code print?

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int *iptr = (int *) 0x1000;

void *a = cptr+4;
void *b = iptr+4;

printf("%p %p\n", a, b);
```

Result: `0x1004 0x1010`

Please vote via Ilias.

Quiz

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char *cptr = (char *) 0x1000;
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void *a = cptr+4;
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```

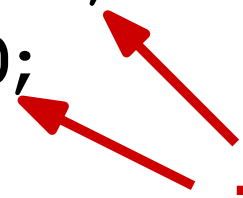

Two pointers initialized with hexadecimal numbers.

Result: `0x1004 0x1010`

Please vote via Ilias.

Quiz

What does the following C code print?

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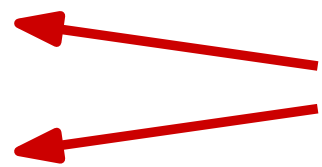


Adding `4*size(t)` to each pointer, where `t` is the type the pointer refers to.

Result: `0x1004 0x1010`

Please vote via Ilias.

Overview

- **Records**
- **Arrays**
- **Pointers and Recursive Types** 
  - Operations on Pointers
  - Pointers and Arrays in C
  - Dangling References
  - Garbage Collection

Motivation

- **Most programs handle complex data**
- **"Linked" data structures to represent them**
  - Lists
  - Trees
  - Graphs
- **Often: Want reference to objects of same type**

Pointers and Recursive Types

- **Pointer: Reference to location of memory object**
  - Essentially, an address
- **Recursive type: Composite type with reference to objects of the same type**

Reference vs. Value Model

PLs with reference model of variables

- No need for explicit pointers
- Fields simply refer to object of same (or other) type

PLs with value model of variables

- Need explicit pointers to refer to objects
- Otherwise, would always copy the entire memory object

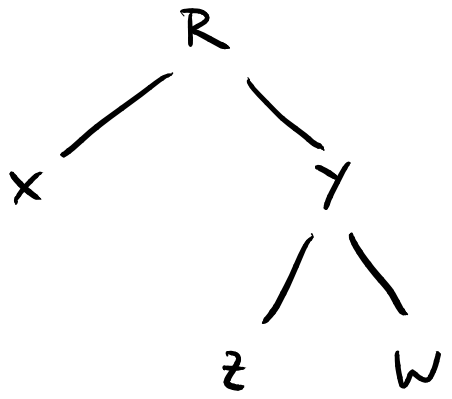
Example: Tree in OCaml

```
type chr_tree =
    Empty |
    Node of char * chr_tree * chr_tree;;
```

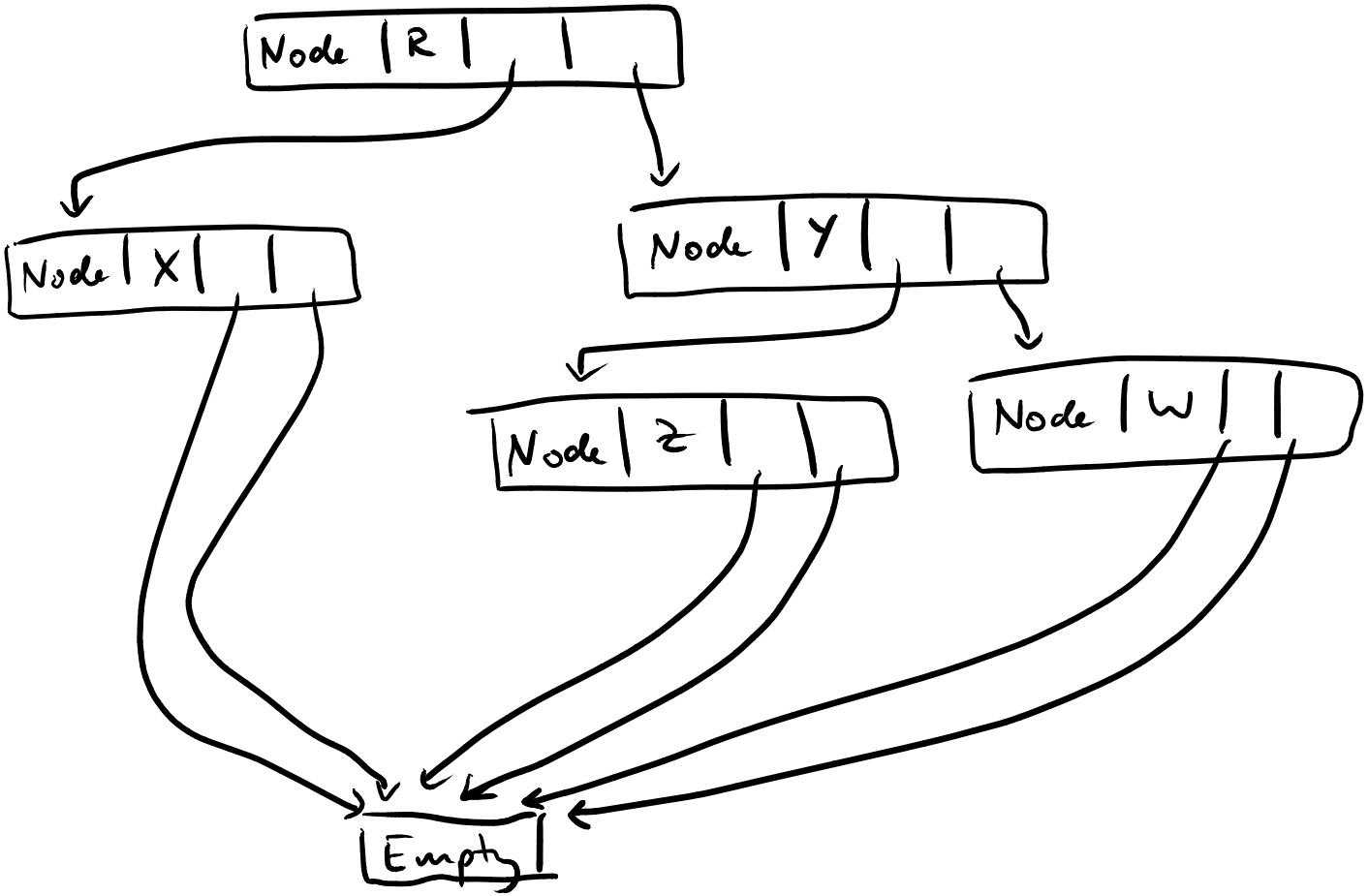
Tuple type with fields separated by *

Example: OCaml

Conceptually:



In memory:

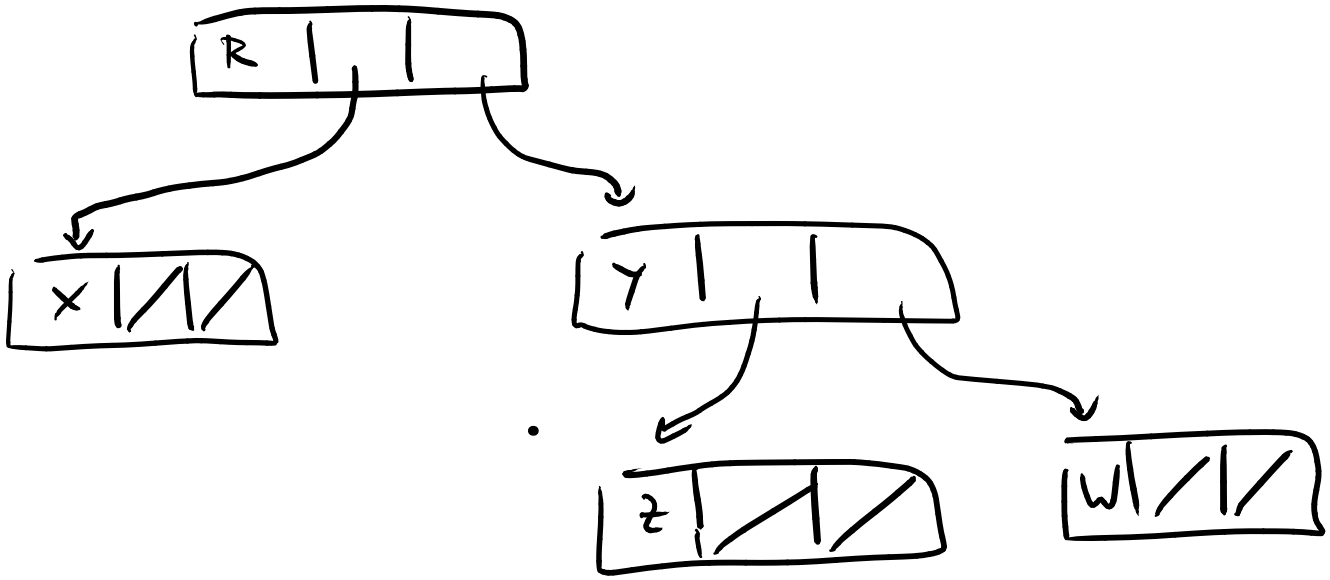


Example: Tree in C

```
struct chr_tree {
  struct chr_tree *left, *right;
  char var;
};
```

Pointers to objects of type `struct chr_tree`

Example: C



/ means null pointer

Operations on Pointers

- Creation
- Allocation
- Dereference
- Deallocation

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Handled differently in different PLs

Creating Pointers

- **Implicit** when calling a constructor
- **Built-in function** that allocates heap memory and returns reference to it
- **Address-of operator**

Creating Pointers

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Example (C++):

```
my_ptr = new chr_tree(/* ... */);
```

Creating Pointers

- **Implicit** when calling a constructor
- **Built-in function** that allocates heap memory and returns reference to it
- **Address-of operator**

Example (C):

```
my_ptr = malloc(sizeof(struct chr_tree));
```

Creating Pointers

- **Implicit** when calling a constructor
- **Built-in function** that allocates heap memory and returns reference to it
- **Address-of operator**

Example (C):

```
int n = 3;
my_ptr = &n;
```

Allocating Memory

- **Pointer itself is only an address**
- **Need sufficient memory to hold the object it refers to**
- **Memory allocation**
  - Implicit on some PLs (e.g., OCaml, Java)
  - Explicit in other PLs (e.g., C)

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Example (OCaml):

```
let t = Node('R', Empty, Empty);;
```

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Example (C):

```
my_ptr = malloc(sizeof(struct chr_tree));
// fill object with content
```

Dereferencing a Pointer

Access memory object a pointer refers to

- Access entire object
  - Dereferencing operator
- Access fields of record that the pointer refers to
  - Right-arrow notation
  - Dot notation:

    Implicit dereferencing

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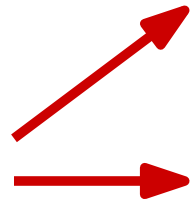

Example (Pascal):

```
my_ptr^.val := 'X';
```

Example (C):

```
(*my_ptr).val = 'X';
```

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  - Right-arrow notation
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Example (C):

```
my_ptr->val = 'X';
```

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- Access entire object
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  - Right-arrow notation
  - Dot notation:

    Implicit dereferencing

Example (Ada):

```
T : chr_tree;
P : chr_tree_ptr;

...
T.val := 'X';
P.val := 'Y';
```

Deallocation

- **Memory must be reclaimed at some point**
  - Otherwise: Memory leak and, eventually, out-of-memory
- **Explicit deallocation by programmer**
  - E.g., C, C++, Rust
- **Implicit deallocation by runtime: Garbage collection**
  - E.g., Java, C#, Python

Deallocation: Example

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

int main(void)
{
    char *line = NULL;
    size_t size = 0;
    for(;;) {
        /* read line from stdin;
           implicitly allocates memory */
        getline(&line, &size, stdin);
        // ...

        line = NULL;
    }
    return 0;
}
```

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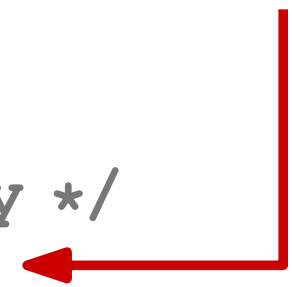
```

Memory leak:
Each iteration allocates memory that gets never freed.



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    for(;;) {
        /* read line from stdin;
           implicitly allocates memory */
        getline(&line, &size, stdin);
        // ...
        free(line);
        line = NULL;
    }
    return 0;
}
```

Fix: Free memory in each iteration

Quiz: Memory Leak

How many bytes of memory are leaked when executing the following code?

Assumption: ints occupy four bytes

```
int *c;
for (int i = 0; i < 5; i += 2) {
    c = malloc(sizeof(int));
    if (i % 4 == 0) {
        free(c);
    }
}
```

Please vote via Ilias.

Quiz: Memory Leak

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Assumption: ints occupy four bytes

```
int *c;
for (int i = 0; i < 5; i += 2) {
    c = malloc(sizeof(int));
    if (i % 4 == 0) {
        free(c);
    }
}
```

Answer: 4 bytes

Please vote via Ilias.