Scope and Code Generation

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COMP 3002

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Scope

- Scoping rules define how variable names are looked up when a program is run or compiled
- We have seen how to implement scoping rules in a typechecker
- How does it work in a code generator?

Run-time Environments

- During execution, each time a function call is made, a new *stack frame* is created to hold all the parameters and local variables for that function call
- Local variables are assigned a position within their stack frame
- A *frame pointer* (fp) keeps track of the top of the current stack frame

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Example of stack frame layout

```
int factorial(int n) {
  if (n == 1) return 1;
  int t = factorial(n-1);
  return n * t;
}
```

```
n (4 bytes)
t (4 bytes)
```

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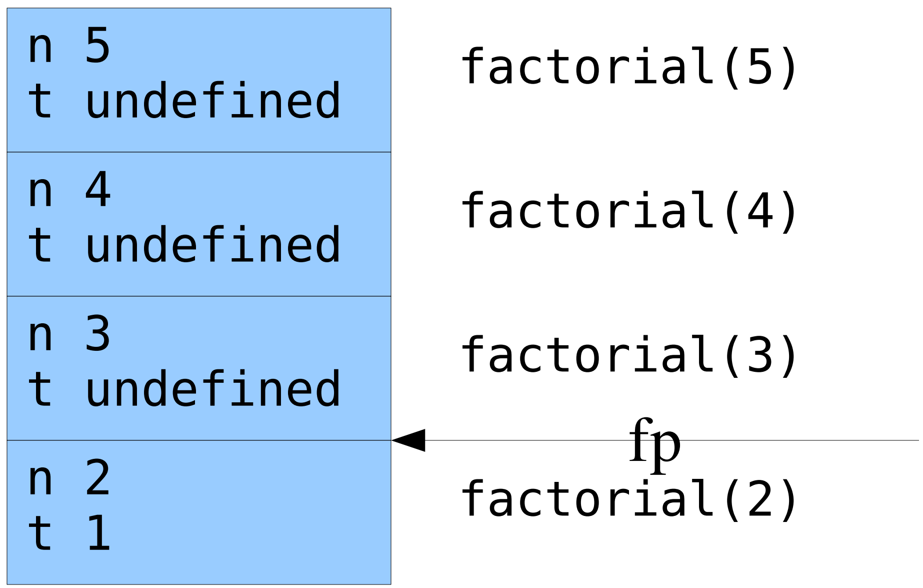
A Runtime Example



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Discussion

- The compiler assigns, to each variable and parameter, a location within the current stack frame
- Operations on local variables are compiled into operations on memory locations relative to the frame pointer (fp)
- But now all variable references are to local variables
  - We assume *static lexical scoping*

A more complicated example

```
int odd_factorial(int q) {
  int factorial(int n) {
    if (n == 1) return q;
    int t = factorial(n-1);
    return n * t;
  }
  if (q % t == 0)
    return t;
  return factorial(t);
}
```

q (4 bytes)

n (4 bytes)
t (4 bytes)

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A Runtime Example

- How do we access q within factorial?

q 5	even_factorial(5)
n 5 t undefined	factorial(5)
n 4 t undefined	factorial(4)
n 3 t undefined	factorial(3)
n 2 t 1	factorial(2)
	fp
n 1 t undefined	

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Solution 1

- Each function has a static level of scope
  - Global scope - level 0
  - even_factorial – level 1
  - factorial – level 2
- Each stack frame contains an extra pointer fpp that points to the stack frame at the next highest level (fpp is actually an implicit parameter)

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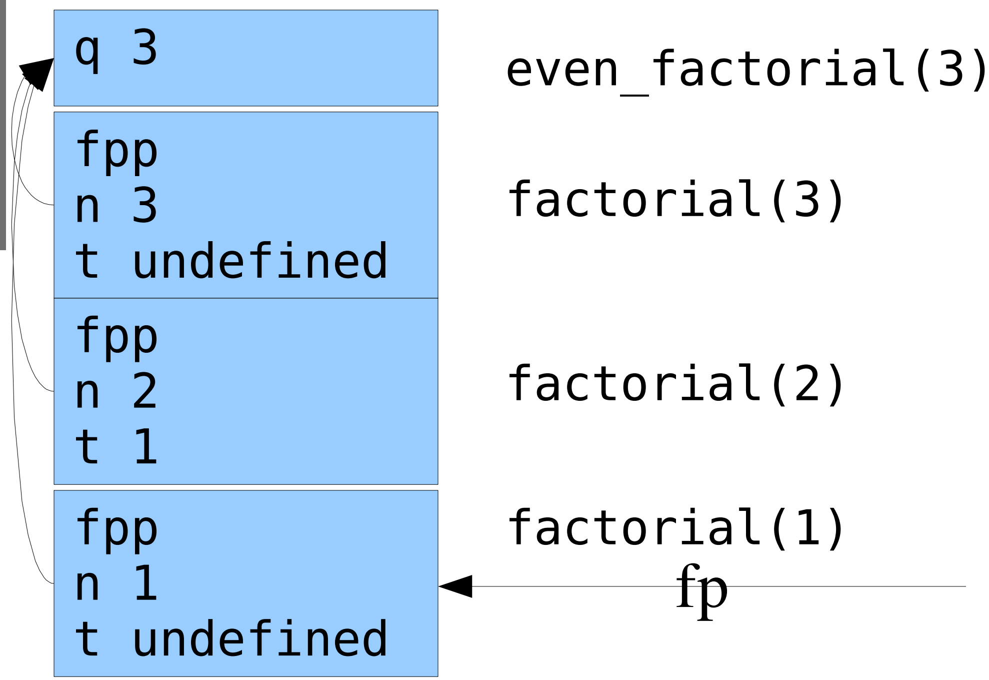
A Runtime Example

- Now we know how to find q from within any recursive call
  - q is at memory location fpp + 0



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Solution 2

- The problem with solution 2 is that it becomes increasingly expensive to access elements that are further away in scope
  - Current level *i*
  - Variable to access is at level *j*>*i*
  - We must follow *j*-*i* fpp pointers
- To speed this up, we can use a global array *frame_pointers*
  - frame_pointers[*i*] is the frame pointer to the *currently active* level *i* frame

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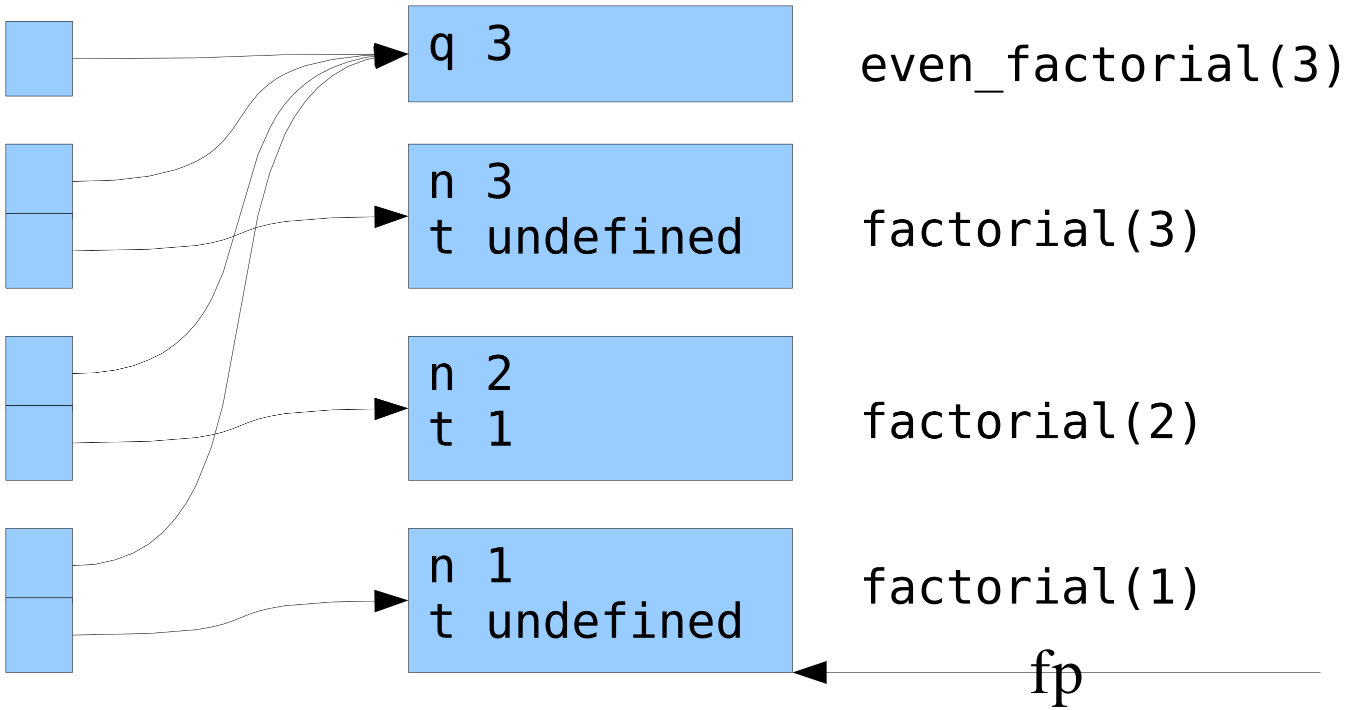
Frame pointer array example



Solution 2 (Cont'd)

- Within a function at level i
  - Save tmp = frame_pointers[*i*]
  - Set frame_pointer[*i*] = fp (current frame pointer)
  - Before returning, restore frame_pointers[*i*] = tmp
- When accessing a variable at level *i* from a level *j* > *i* we can get the correct frame pointer just by looking at frame_pointers[*i*]

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Solution 1 versus Solution 2

- Whether to use Solution 1 or 2 depends on how often variables at higher levels of scope are accessed
  - Solution 1 is more costly when accessing variables that are at much higher scope levels
  - Solution 2 increases the cost of every function call but makes all variable accesses constant time

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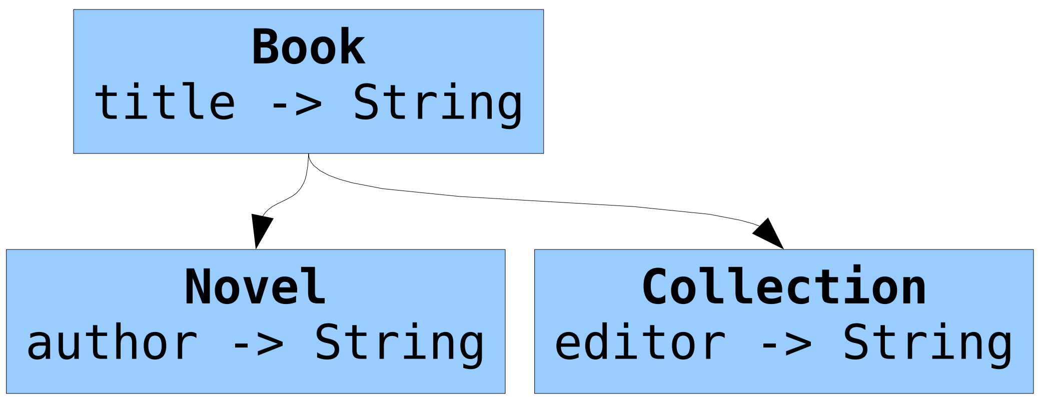
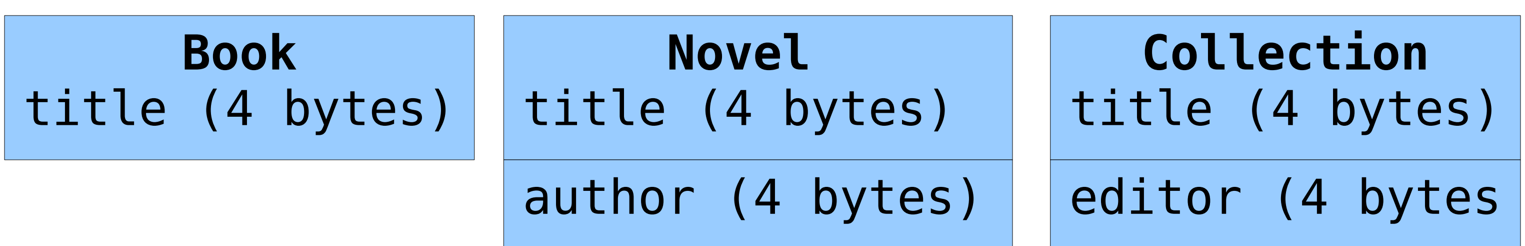
What About Objects?

- For compilers, objects are just structures
- When calling a method on an object, an implicit pointer to the object is passed (*this* or *self*) to the method
- Inheritance is handled by having the child class inherit the structure of the parent and then add on its own elements

Inheritance Example

- Any method that assumes the memory layout of a Book can be used on a Novel or a Collection





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"Virtual" Methods

- For each "virtual" object method, a new instance variable can be created
- When a child class overrides a method in a parent class, the instance variable is just overridden

Book	Novel	Collection
`title (4 bytes)` `fnPrint -> printBook`	`title (4 bytes)` `fnPrint -> printNovel`	`title (4 bytes)` `fnPrint -> printColl`
	`author (4 bytes)`	`editor (4 bytes)`

"Virtual" Methods (Cont'd)

- Virtual methods require two extra levels of indirection
  - Lookup the function address in *this* or *self* (1 level)
  - Load the function address and call it
- For this reason, some languages (C++ and Java) mix "virtual" and non-virtual functions
  - In C++ the virtual keyword is used to specify virtual functions (all others are non-virtual)
  - In Java, the final keyword is used to specify non-virtual functions (these can't be overridden by a subclass)

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Summary

- A compiler must resolve occurrences of a variable to the memory location of that variable
- For static lexical scoping, this is done using parent frame pointers (fpp)
  - 2 solutions:
    - 1 - slower lookup for deeply nested functions
    - 2 - slower function calls but faster lookup
- For objects, this is even easier
  - Objects inherit their structure from their parents
  - "Virtual" functions are just instance variables

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