INF3110 – Programming Languages
Runtime Organization part II

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Slides adapted from previous years' slides made by Birger Møller-Pedersen

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Today: Higher-Order Functions, and Objects at runtime

- Higher-order functions:
  - Functions passed as arguments
  - Functions that return functions from nested blocks
  - Need to maintain environment of function
- Simpler case
  - Function passed as argument
  - Need pointer to activation record “higher up” in stack
- More complicated case
  - Function returned as result of function call
  - Need to keep activation record of returning function

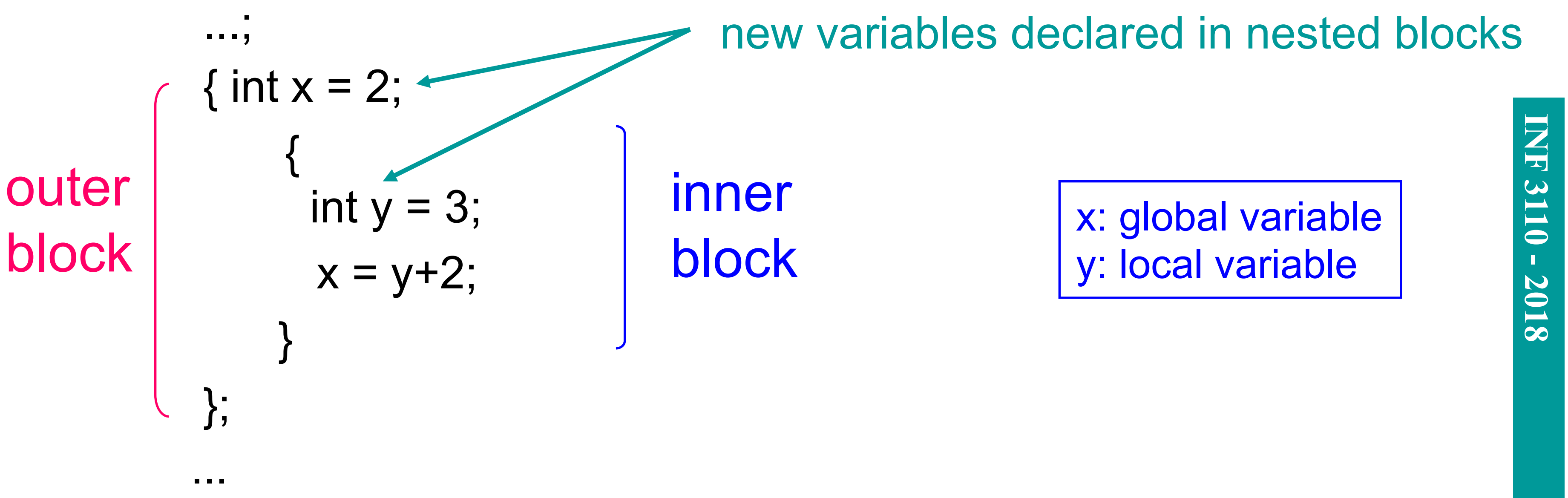
- Objects at runtime
  - Which activation blocks do we use?

- Fun with Javascript
  - The worlds most popular(?) language!
  - Heavy use of higher-order functions

Repetition from last time

Block-Structured Languages

- Blocks are *syntactical* structures
- Can be nested within each other



```
…;
{ int x = 2;
      {
        int y = 3;
        x = y+2;
      }
};
…
```

new variables declared in nested blocks

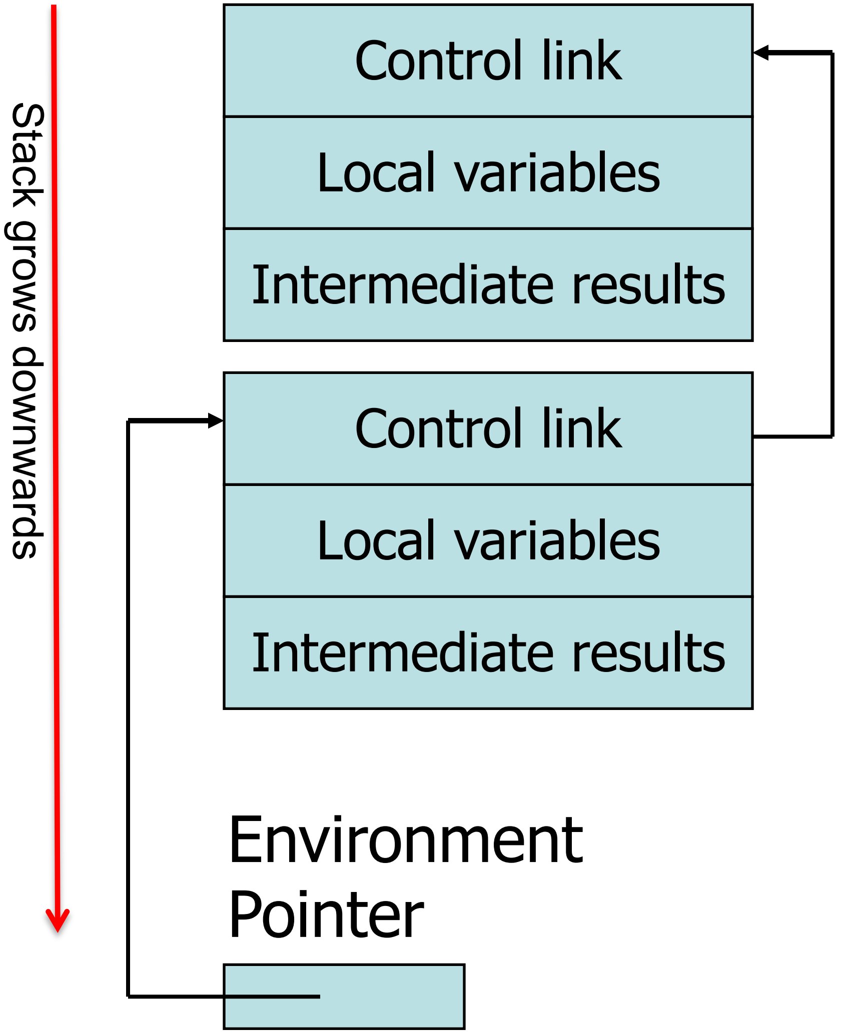
outer block

inner block

x: global variable
y: local variable

- Storage management – memory representation
  - Enter block: allocate space for variables
  - Exits block: space *may* be de-allocated

Activation record for in-line block



- Environment pointer
  - Pointer to current record on stack
- Control link (dynamic link)
  - Pointer to previous record on stack
  - Why is it called *dynamic*?
- Push record on stack
  - Set new control link (in new record) to point to old env ptr
  - Set env ptr to new record
- Pop record off stack
  - Follow control link of current record to reset environment pointer
  - (No need to actively blank memory)

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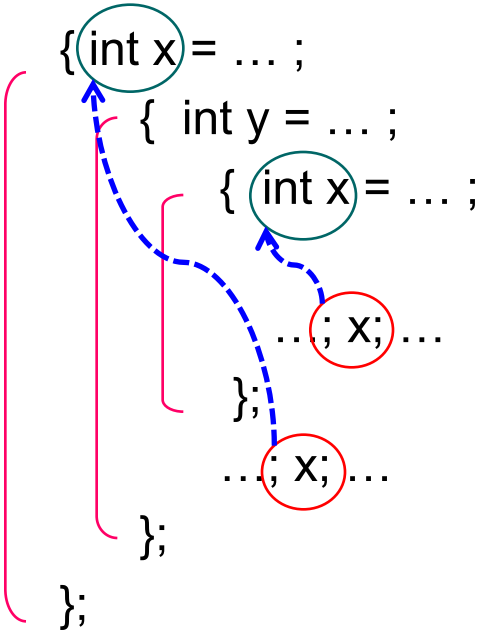
Some basic concepts

- Scope
  - Region of program text where declaration is visible
- Lifetime
  - Period of time when location is allocated



```
{ int x = … ;
    { int y = … ;
        { int x = … ;
            …; x; …
        };
        …; x; …
    };
};
```

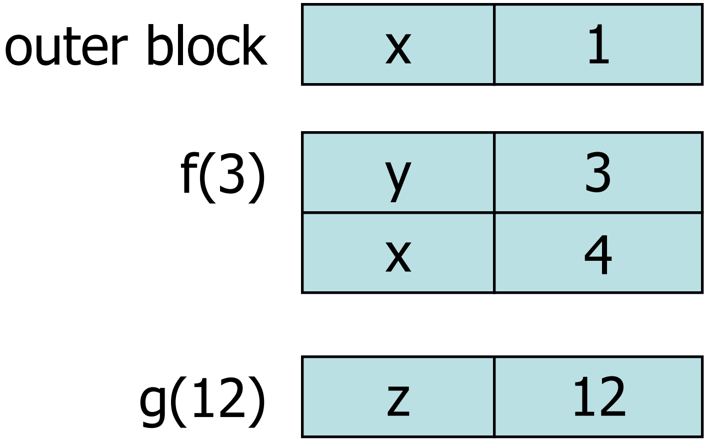
- Inner declaration of x hides outer one.
- Called “hole in scope”

- Lifetime of outer x includes time when inner block is executed
- Lifetime ≠ scope

Access to global variables

- Two possible scoping conventions
  - Static scope: refer to closest enclosing block (syntactically)
  - Dynamic scope: most recent activation record on stack
- Example

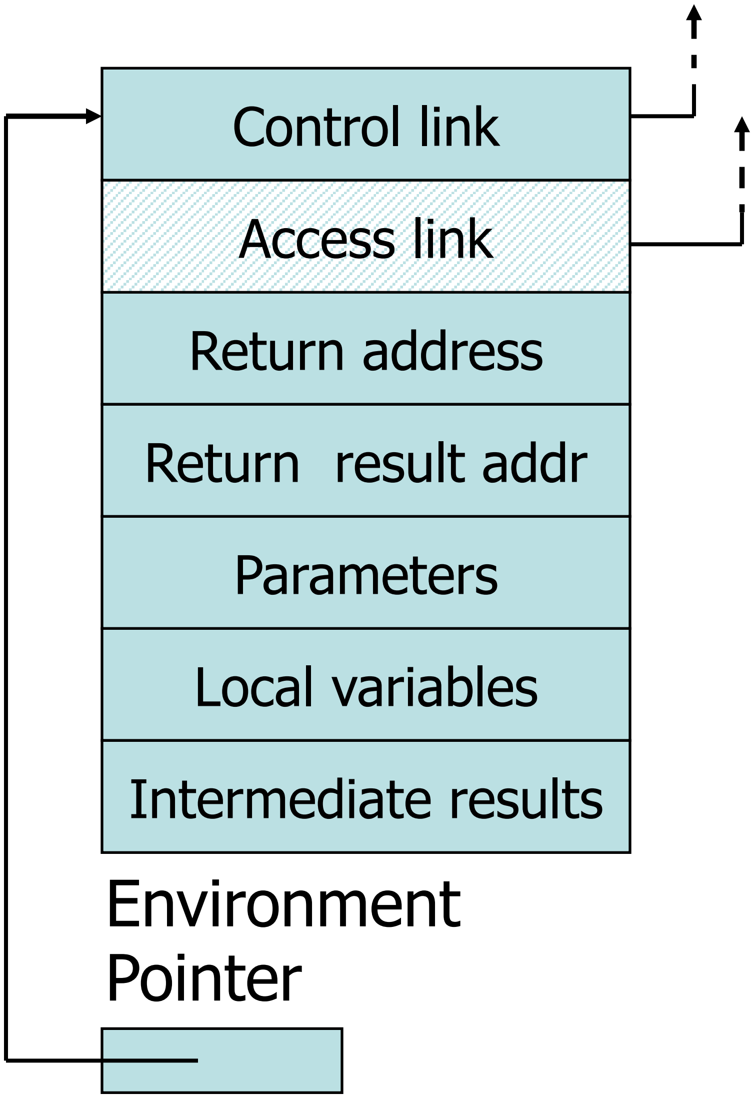
```
int x = 1;
function g(z) = x+z;
function f(y) =
    {
      int x = y+1;
      return g(y*x)
    };
f(3);
```



outer block	x	1
f(3)	y	3
	x	4
g(12)	z	12

How do we know which x is used for expression x+z?

Activation record for static scope



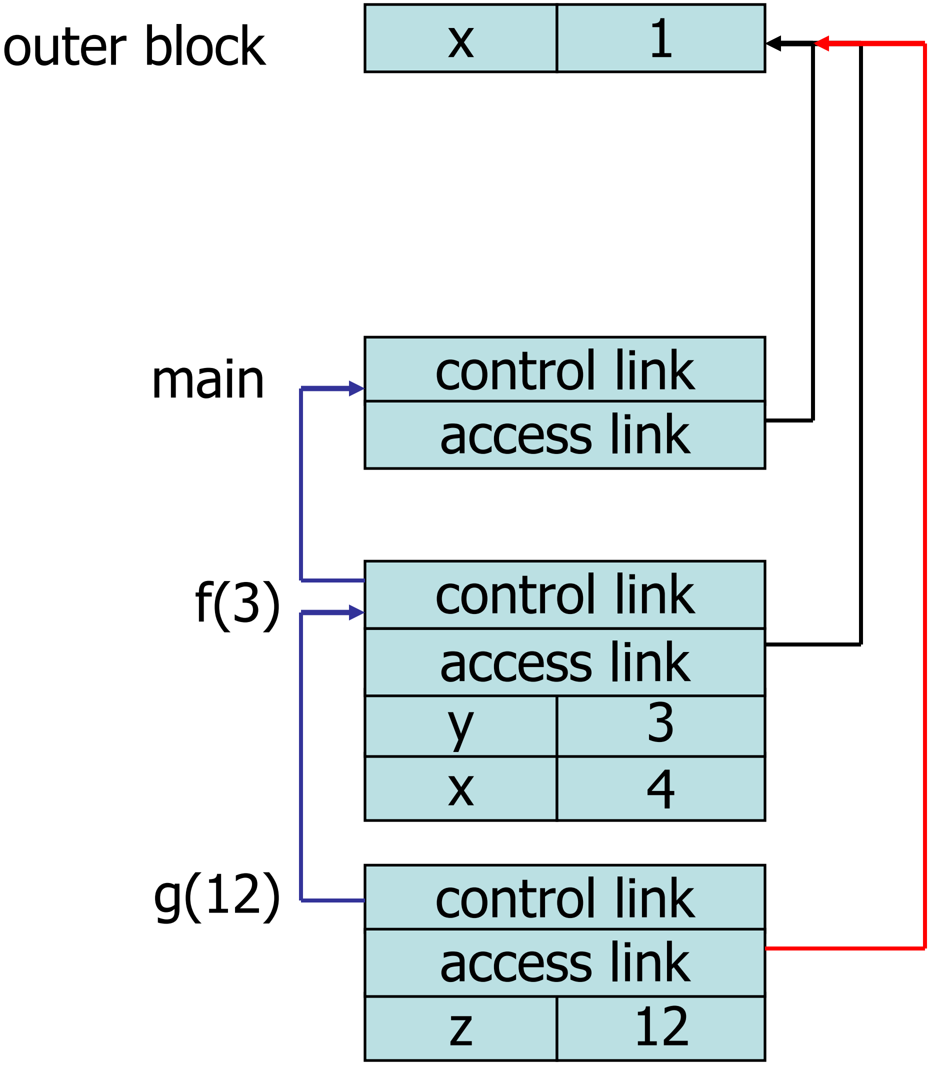
- Control link (dynamic link)
  - Link to activation record of previous (calling) block
- Access link (static link)
  - Link to activation record corresponding to the closest enclosing block in program text
  - Why is it called *static*?
- Difference
  - Control link depends on dynamic behavior of program
  - Access link depends on static form of program text

Simple example for a language with blocks and functions

```
{
  int x = 1;
  int function g(z) {
       return x+z
  };

  int function f(y) {
     int x = y+1;
     return g(y*x)
  };

  main() {
    f(3);
  }
}
```



outer block

x	1

main

control link

access link

f(3)

control link

access link

y	3
x	4

g(12)

control link

access link

z	12

FORWARD
WITHOUT FEAR

Functions as parameters: why?

Given a Person class and a list of Persons

Can you write a function that finds all persons that

- Are female?
- Are older than 50 years?
- Like drinking beer?

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Functions as parameters: why?

Given a Person class and a list of Persons

Can you write a function that finds all persons that

- Are female?
- Are older than 50 years?
- Like drinking beer?

A first attempt:

```
List<Person> findPersonsThatAreFemale(List<Person> persons) {
    List<Person> filteredList = new List<Person>();
    for(Person p in persons) {
        if(p.gender == ”female”) {
            filteredList.Add(p);
        }
    }
    return filteredList;
}
```

Functions as parameters: why?

Given a Person class and a list of Persons

Can you write a function that finds all persons that

- Are female?
- Are older than 50 years?
- Like drinking beer?
- …

A first attempt:

```
List<Person> findPersonsThatAreOlderThan50(List<Person> persons) {
    List<Person> filteredList = new List<Person>();
    for(Person p in persons) {
        if(p.age > 50) {
            filteredList.Add(p);
        }
    }
    return filteredList;
}
```

Why functions as parameters? – DRY!

```
List<Person> filterPersons(List<Person> persons, (Person → Boolean) filter) {
    List<Person> filteredList = new List<Person>();
    for(Person p in persons) {
        if(filter(p)) {
            filteredList.Add(p);
        }
    }
    return filteredList;
}
```

Imaginary func syntax

```
filterPersons( persons, function(Person p) { return p.age > 50 } );

filterPersons( persons, function(Person p) { return p.gender == ”female” } );
```

Is this in use in languages today?

Traditional OO approach: make a class out of it!

E.g. in Java (pre v8):

```
Collections.sort(list, new Comparator<MyClass>() {
    public int compare(MyClass a, MyClass b)
    {
        // compare objects here
    }
});
```

What is going on here?

- Comparator<T> is an interface, and T is a type parameter
- This interface has one method signature, int compare(T a, T b);
- Starting from the first {, we have an anonymous class implementing this interface

Is this in use in languages today?

Functional approach:

- Java (v8 and up):

```
list.sort((a, b) -> a.isGreaterThan(b));
```

- C#:

```
myList.Where(a => a.Number > 42).OrderBy(a => a.Number)
        .ThenBy(a => a.FooBar);
```

- Python:

```
Celsius = [39.2, 36.5, 37.3, 37.8]
Fahrenheit = map(lambda x: (float(9)/5)*x + 32, Celsius)
```

- JavaScript (Node):

```
app.get('/somepath/:date', function (req, res)
  res.setHeader('Content-Type', 'application/json');
  fetchStuff({ date: req.params.date}, function (error, result) {
      if (error) console.log(error);
      res.end(result);
    });
});
```

Pass function as argument

There are two declarations of x

Which one is in scope for each usage of x?

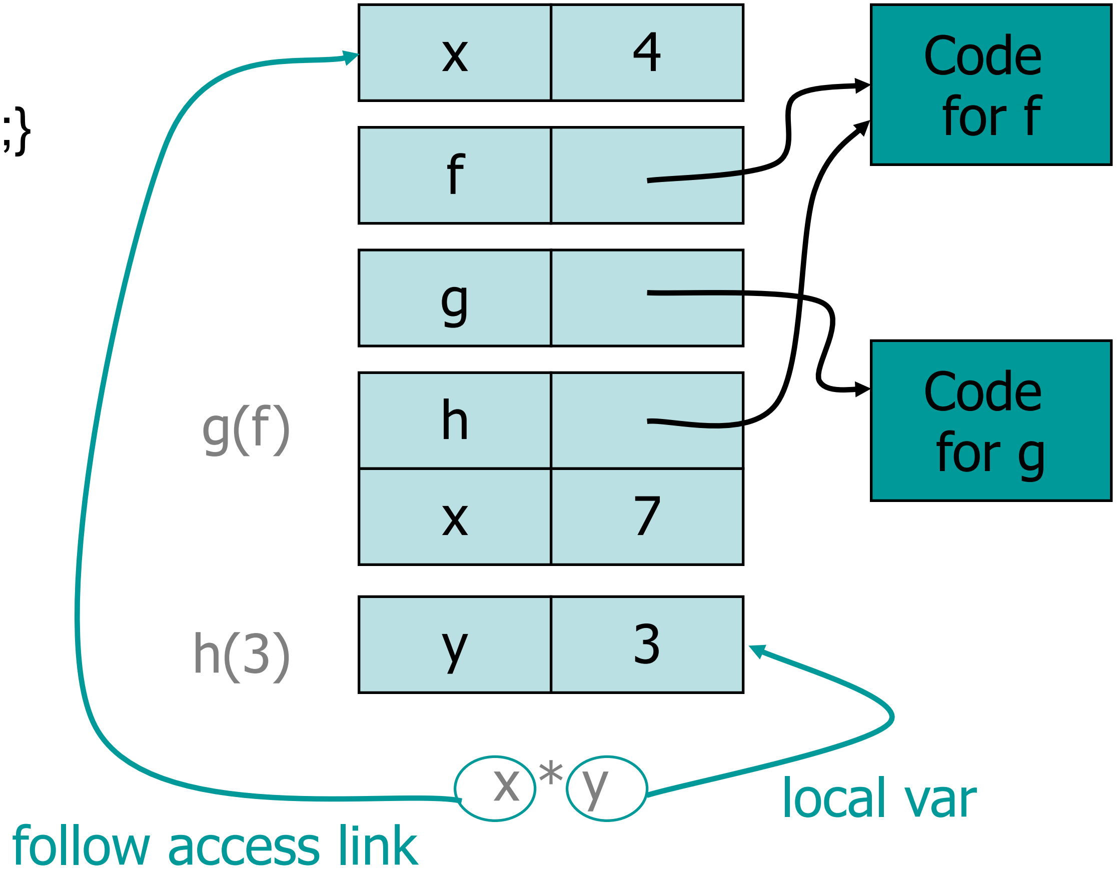
```
{ int x = 4;
  { int f(int y) {return x*y;}
     { int g(int→int h) {
              int x=7;
              return h(3) + x;
           }
        g(f);
     }
  }
}
```

Formal function parameter

Actual function parameter

Static Scope for Function Argument

```
{ int x = 4;
  { int f(int y) {return x*y;}
     { int g(int→int h) {
             int x=7;
             return h(3) + x;
             }
        g(f);
    }
  }
}
```



How is access link for h(3) set? → Next slides

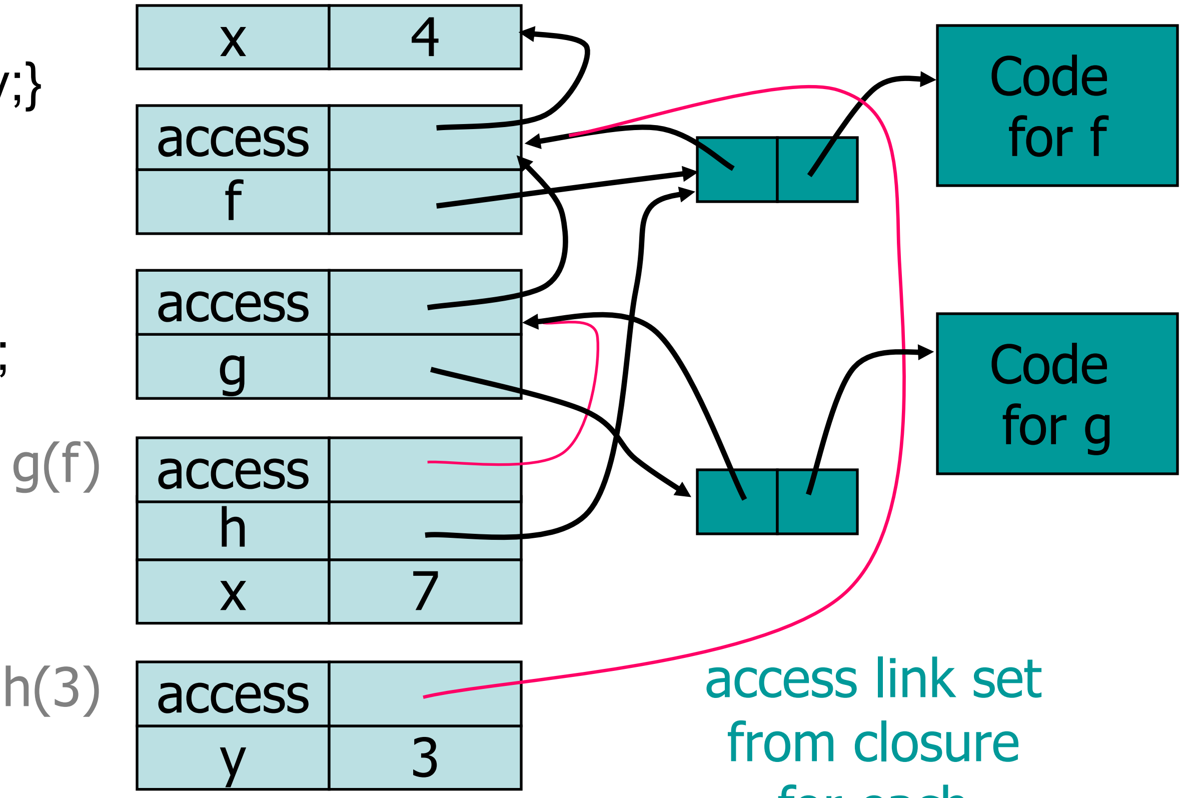
Closures

- Function value is pair *closure* = ⟨*env*, *code* ⟩
- When a function represented by a closure is called
  - Allocate activation record for call (as always)
  - Set the access link in the activation record using the environment pointer from the closure

Function Argument and Closures

```
{ int x = 4;
   { int f(int y){return x*y;}
      { int g(int→int h) {
            int x=7;
            return h(3)+x;
         }
         g(f);
      }
   }
}
```

Run-time stack with access links



access link set from closure for each function call

Return Function as Result

- Language feature
  - Functions that return "new" functions
  - Need to maintain environment of function

- Function "created" dynamically
  - function value is closure = ⟨env, code⟩
  - code *not* compiled dynamically (in most languages)

Example: Return function with private state

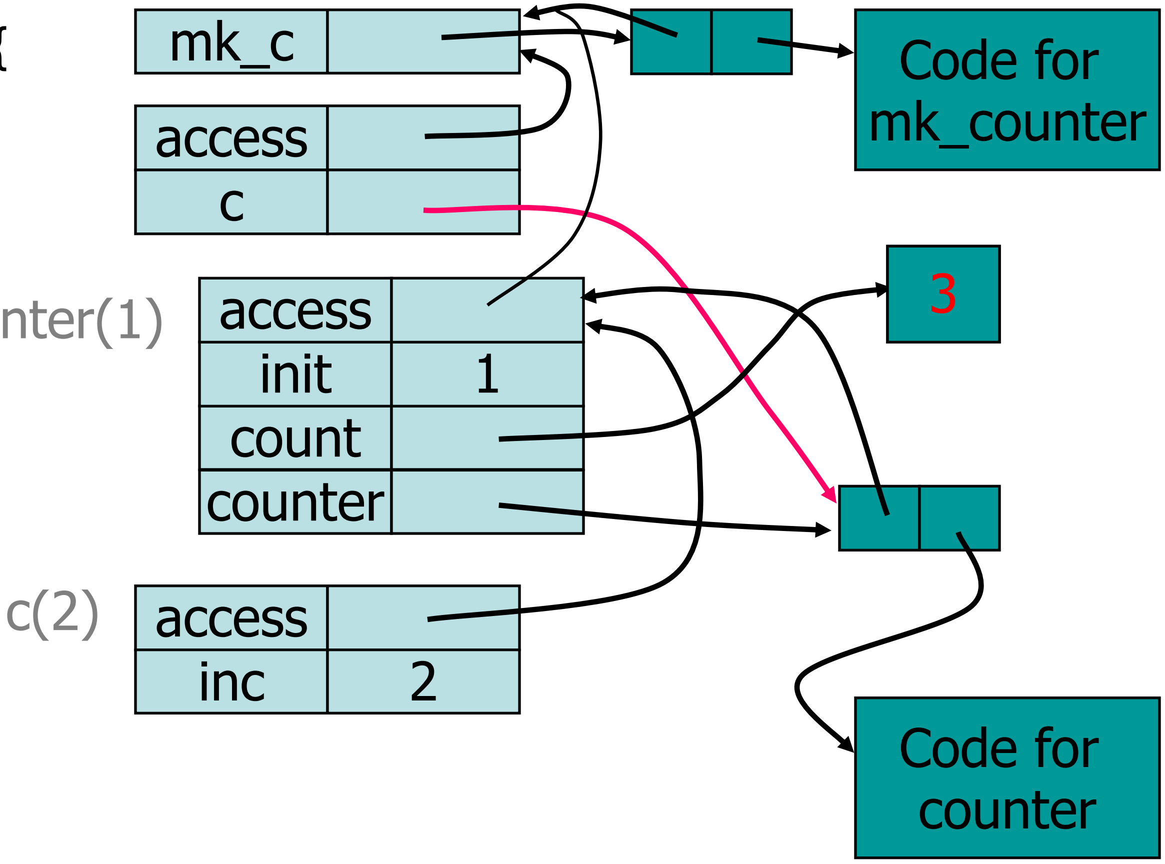
Function “make counter” returns a closure

```
{ int→int mk_counter (int init) {
      int count = init;
      int counter(int inc)
         { return count += inc;}
      return counter
  }
  int→int c  = mk_counter(1);
  print c(2) + c(2);
}
```

How is correct value of count determined in call c(2) ?   Next slide →

Function Results and Closures

```
{int→int mk_counter (int init) {
      int count = init;
      int counter(int inc)
         { return count+=inc;}
      return counter
      }
  int→int c = mk_counter(1);
  print c(2) + c(2);
}
```



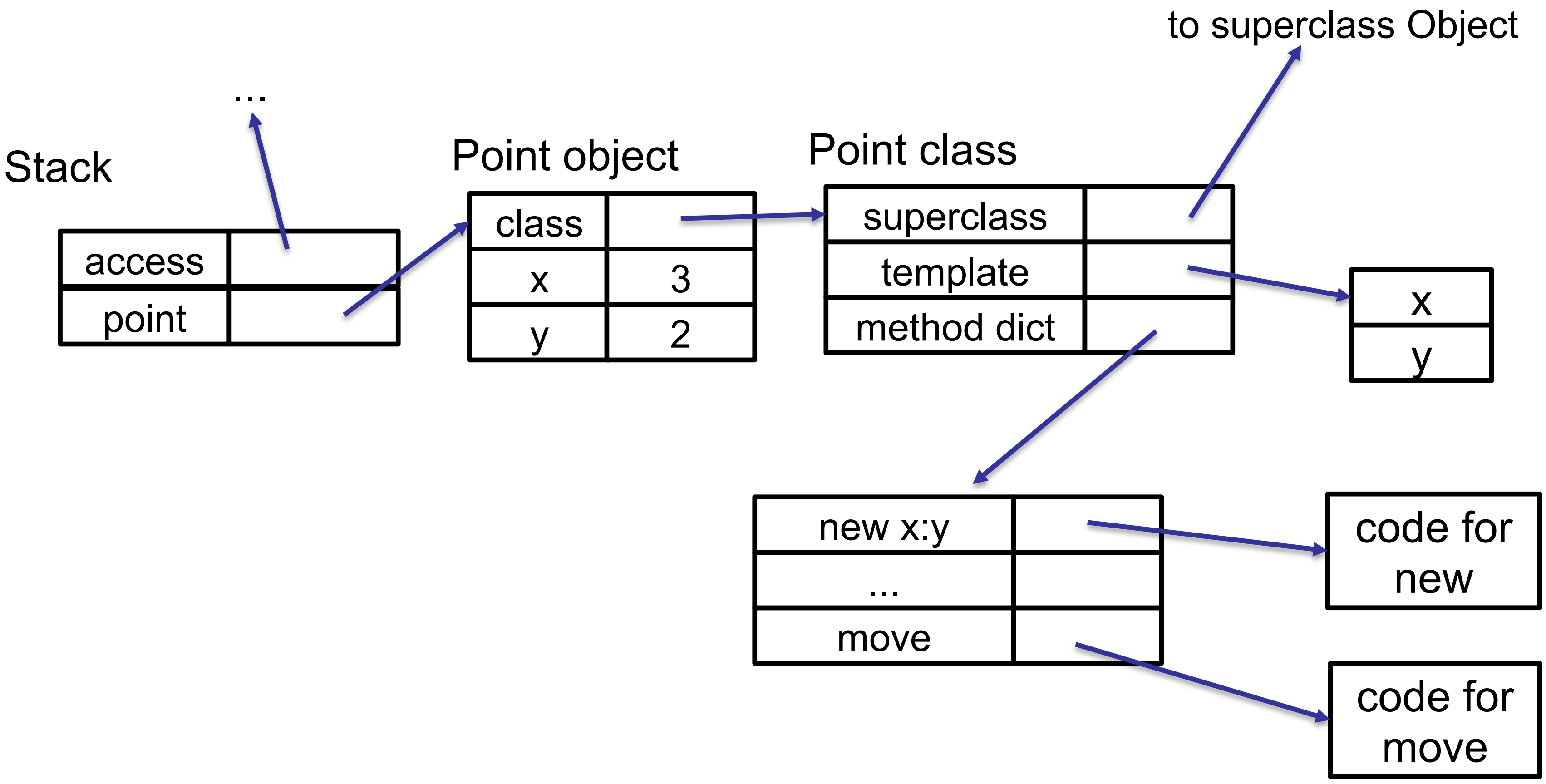
Call changes cell value from 1 to 3

Activation record associated with returned function cannot be deallocated upon function return

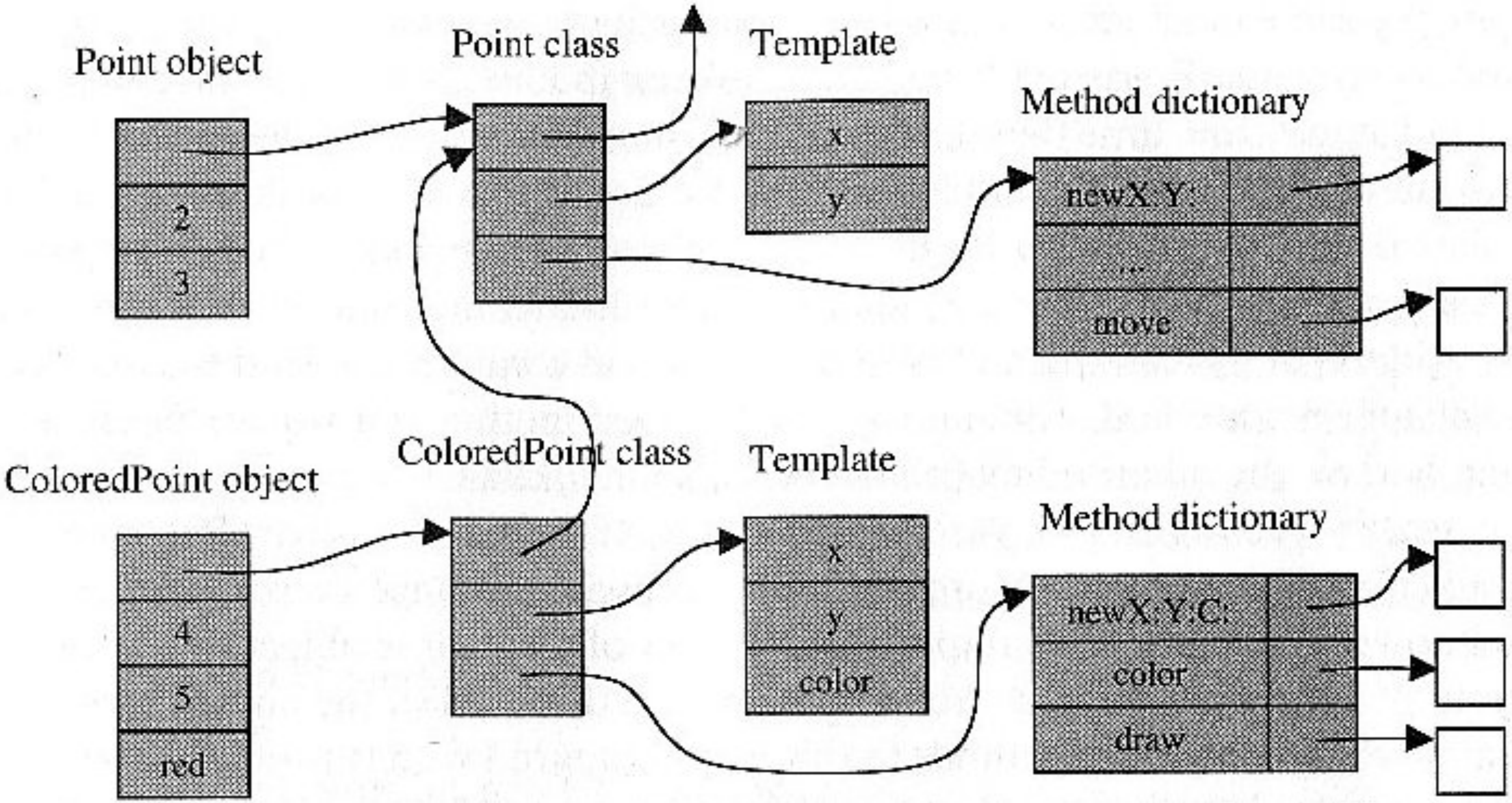
Classes and objects at runtime

- Pointers to objects on the stack
  - In “normal” activation bloks
- The objects themselves are typically not stored on the stack
  - Separate location called the heap
- Data for each object stored with the object
  - E.g. x and y coordinates for a point
- Common functionality stored in shared location
  - Methods, static variables

Smalltalk – Point object and class



Smalltalk – runtime support for inheritance



Aside: not all scopes are equal

```
this.value = 42; //Global variable

var obj = {
    value: 0, //Local field in object
    increment: function() {
        this.value++;
        alert(this.value);

        var innerFunction = function() {
            alert(this.value);
        }

        innerFunction(); // Function invocation
    }
}
obj.increment(); // Method call
```

What will be shown on screen?

Try it out yourselves: http://jsfiddle.net/7jxw1r9v/1/

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How do we fix this?

```
this.value = 42; //Global variable

var obj = {
    value: 0,
    increment: function() {
        this.value++;
        alert(this.value);
        var that = this;

        var innerFunction = function() {
            alert(that.value);
        }

        innerFunction(); //Function invocation
    }
}
obj.increment(); //Method invocation
```

Why does this help?

Because this function is a closure that captures the «that» variable

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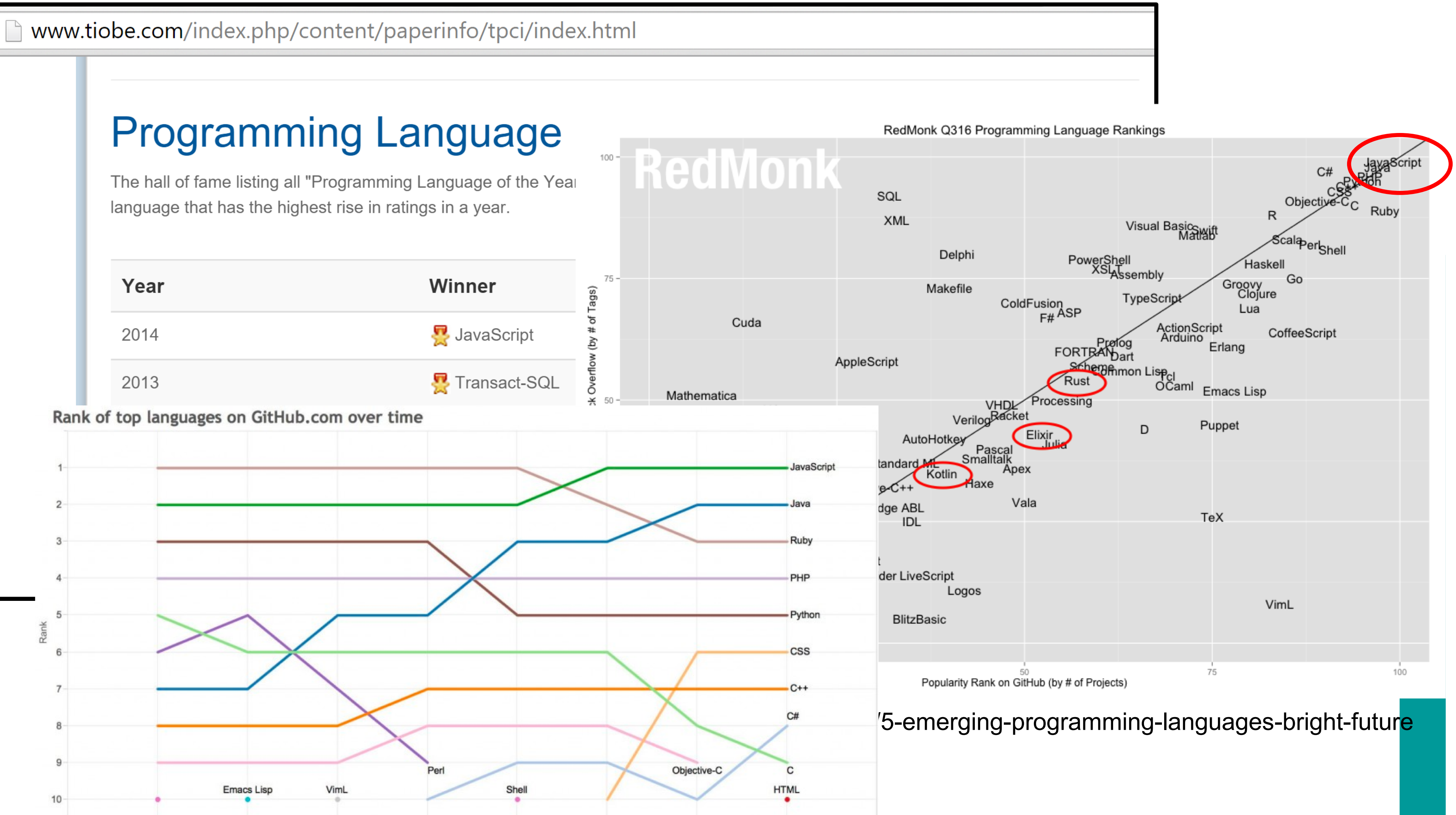
Everyone loves Javascript!



www.tiobe.com/index.php/content/paperinfo/tpci/index.html

Programming Language

The hall of fame listing all "Programming Language of the Yea
language that has the highest rise in ratings in a year.

Year	Winner
2014	JavaScript
2013	Transact-SQL

'5-emerging-programming-languages-bright-future

https://www.destroyallsoftware.com/talks/wat

But WHY all these WATs?

- JavaScript has automatic type coercion
  - It will try to convert types into something that matches the operand!
- [ ] + [ ] = ""
  - The + operator cannot operate on arrays, so the array is *coerced* to its string representation, which is a toString() of all the elements joined by commas.
- { } + [ ] = 0
  - The first is recognized as an empty code block.
  - The plus is thus unary, and [ ] is coerced to an empty string, which is in turned coerced to 0.
- { } + { } = NaN
  - The first is again an empty code block
  - The second { } is an empty object, which is coerced to [object Object], which is the toString() repr of objects
  - Which is again not a number, or NaN

More fun: scoping and blocks

Java:

```
void main() {
    Integer x = 1;
    System.out.println(x);
    if (true) {
        Integer x = 2;
        System.out.println(x);
    }
    System.out.println(x);
}
```

Output: «1», «2», «1»

JavaScript:

```
function main() {
    var x = 1;
    console.log(x);
    if (true) {
        var x = 2;
        console.log(x);
    }
    console.log(x);
}
```

Output: «1», «2», «2»!

- JavaScript has blocks, but (traditionally) not block scope!
- Declarations are always «hoisted» to the top of the function

More fun: scoping and blocks

Java:

```
void main() {
    Integer x = 1;
    System.out.println(x);
    if (true) {
        Integer x = 2;
        System.out.println(x);
    }
    System.out.println(x);
}
```

Output: «1», «2», «1»

JavaScript, explicit hoisting:

```
function main() {
    var x;
    var x;
    x = 1;
    console.log(x);
    if (true) {
        x = 2;
        console.log(x);
    }
    console.log(x);
}
```

Output: «1», «2», «2»!

- JavaScript has blocks, but (traditionally) not block scope!
- Declarations are always «hoisted» to the top of the function

More fun: scoping and blocks

Java:

```
void main() {
    Integer x = 1;
    System.out.println(x);
    if (true) {
        Integer x = 2;
        System.out.println(x);
    }
    System.out.println(x);
}
```

Output: «1», «2», «1»

JavaScript/*EcmaScript 6*+:

```
function main() {
    let x = 1;
    console.log(x);
    if (true) {
        let x = 2;
        console.log(x);
    }
    console.log(x);
}
```

Output: «1», «2», «1»!

- EcmaScript 6 has blocks *and* block scope, if you use ”let”!

Upcoming!

- Autumn vacation study-week
- Oblig 2 out October 5th, in October 26th
- OO lecture part II