Hack Your Language!

CSE401 Winter 2016
Introduction to Compiler Construction

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Lecture 8: Implementing Reactive Programming 2

More Continuation-passing style
Implementing event handlers

schmarrows

education version of arrowlets

Our goal

Write a JavaScript program with this behavior:

- print 1
- print 2
- wait for a click
- print 3
- print 4
- sleep for 1 second
- print 5
- print 6

Design an *DSL* with readable syntax, embedded in JS.

- Namely, *shallowly* embedded: constructs are calls to a JS lib
- *Deep embedding* is when the program exists as data, eg AST

Our starter skeleton

```
<body onload= "start()">

function start() { ??           }
function f1()    { print(1); }
function f2()    { print(2); }
function click() { document.getElementById("myBtn").onclick = ??; }
function f3()    { print(3); }
function f4()    { print(4); }
function sleep() { setTimeout(??, 1000); }
function f5()    { print(5); }
function f6()    { print(6); }
```

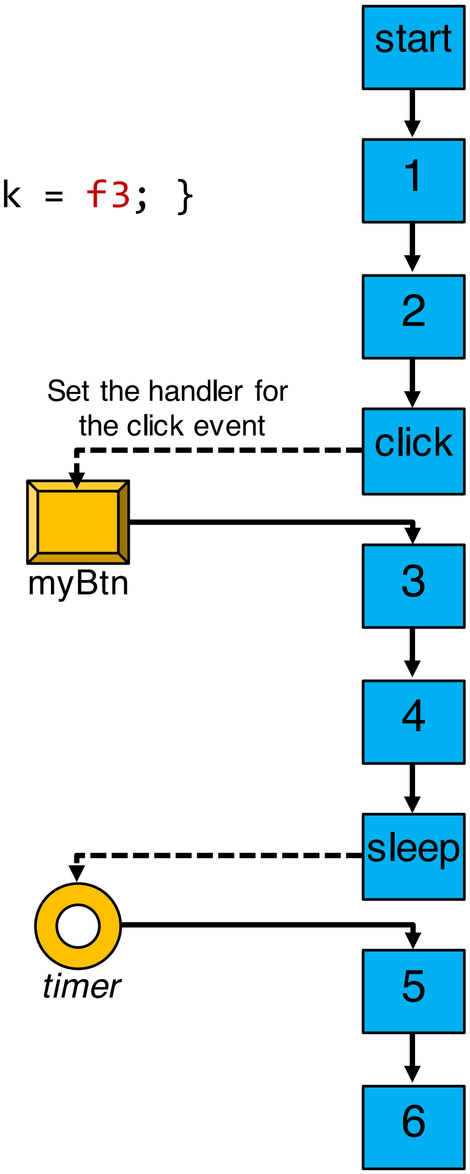
Replace ?? with functions or function calls.

The complete starter skeleton

```
<html>
<head></head>
<body onload= "start()">

<div></div>
<button id="myBtn">Click me</button>

<script>
function start() {              }
function f1()    { print(1); }
…
function f6()    { print(6); }

function print(s) {
  document.body.children[0].appendChild(document.createTextNode(s);
}
</script>
</body>
```

1. A working solution, but unsatisfying

```
function start() { f1(); }
function f1()    { print(1); f2();    }
function f2()    { print(2); click(); }
function click() { document.getElementById("myBtn").onclick = f3; }
function f3()    { print(3); f4();    }
function f4()    { print(4); sleep(); }
function sleep() { setTimeout(f5, 1000); }
function f5()    { print(5); f6(); }
function f6()    { print(6); }
```



We transfer the control correctly

including via event handlers!

Why is this program unsatisfying?

Modifies the implementation of work functions f1..6

- Typically, we have only references to functions, not the code
- This also prevents us from calling any of these functions twice

The hardcoded calls to f1..6 are equivalent to goto:

```
        goto Label1:
        ...
Label1: ...
```

2. A fix: parameterize the work functions

```
function f1k(k)    { print(1); k(); }
function f2k(k)    { print(2); k(); }
function clickk(k){ document.getElementById("myBtn").onclick = k; }
function f3k(k)    { print(3); k(); }
function f4k(k)    { print(4); k(); }
function sleepk(k){ setTimeout(k, 1000); }
function f5k(k)    { print(5); k(); }
function f6k(k)    { print(6); k(); }
```

The value passed to k is a *continuation*

- a closure that executes "the rest of the program execution"

Continuation-passing style: when functions call continuations

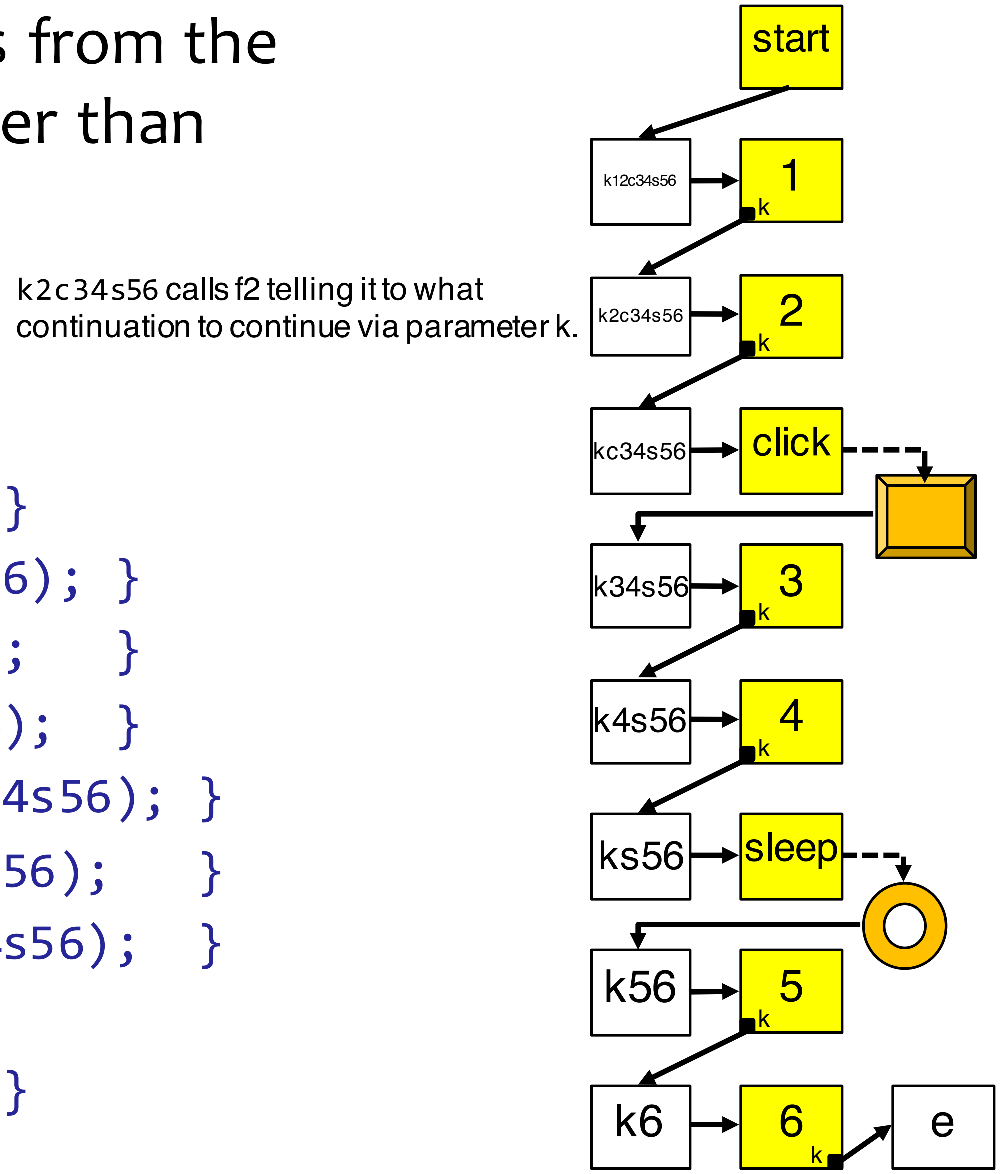
- rather than returning (we'll name such functions f1k)

A **cps** program never returns (only at the very end)

- continuation calls are tail calls (no need to push frames to call stack)

Setting up the continuations

Should we define continuations from the end of the execution? Yes, easier than from the front.




```
function          e() { }
function         k6() { f6k(e); }
function        k56() { f5k(k6); }
function       ks56() { sleepk(k56); }
function      k4s56() { f4k(ks56);   }
function     k34s56() { f3k(k4s56);  }
function    kc34s56() { clickk(k34s56); }
function   k2c34s56() { f2k(kc34s56);   }
function  k12c34s56() { f1k(k2c34s56);  }

function start() { k12c34s56(); }
```

3. Better yet: avoid direct modification of f1..6

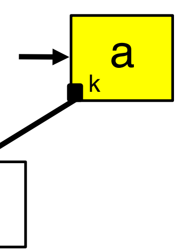
```
function  cps(f) { return function(k) { f(); k() } }

// cps(f1) turns function f1()   { print(1) }
// into          function f1k(k) { print(1); k(); }

function          e() { }
function         k6() { cps(f6)(e); }
function        k56() { cps(f5)(k6); }
function       ks56() {  sleepk(k56); }
function      k4s56() { cps(f4)(ks56);   }
function     k34s56() { cps(f3)(k4s56);  }
function    kc34s56() {  clickk(k34s56); }
function  k2c34s56() { cps(f2)(kc34s56);   }
function k12c34s56() { cps(f1)(k2c34s56);  }

function start() { k12c34s56(); }
```

Exercise

Draw the connections between functions after the code on the previous slide executes.

Instructions:

- Each function is a box
- Boxes a, b are connected if a calls b
  - Use the small black box to show that b is a continuation of a



Taking stock

Our work functions f1..6 are unmodified (yay!)

But do we want our programmers write this code?!?

```
function         e() { }
function        k6() { cps(f6)(e); }
function       k56() { cps(f5)(k6); }
function      ks56() {  sleepk(k56); }
function     k4s56() { cps(f4)(ks56);   }
function    k34s56() { cps(f3)(k4s56);  }
function   kc34s56() {  clickk(k34s56); }
function  k2c34s56() { cps(f2)(kc34s56);  }
function k12c34s56() { cps(f1)(k2c34s56); }
```

Are you bored?

For those needing a challenge, implement function `seq` that allows composition as close as possible to this:

```
// compose f1..6, don't call them yet
c = seq(f1)(f2)(f3)(f4)(f5)(f6)

c() // f1..f6 are called now
```

Write `seq` with lambdas only, without arrays or objects

For the rest of us …

How our composition code should look like.

We want to write code as close as possible to this:

```
var c = f1.next(f2) // compose the steps
          .click()
          .next(f3)
          .next(f4)
          .sleep()
          .next(f5)
          .next(f6);
c.run()    // now run the composition
```

4. Stepping stone (forward composition)

As a prep step, we change this **backward** composition

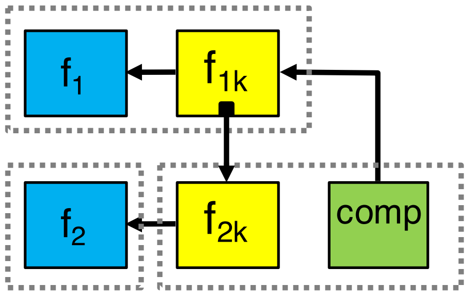
```
function         e() { }
function        k6() { wrap(f6)(e); }
function       k56() { wrap(f5)(k6); }
function      ks56() {    sleep(k56); }
…
function k12c34s56() { wrap(f1)(k2c34s56); }
```

into a **forward** composition, roughly as follows

```
function    f12() { … composes f1 and f2 … }
function   f12c() { … composes f12 and the wait on click … }
function  f12c3() { … composes f12c and f3 … }
…
```

The actual composition code

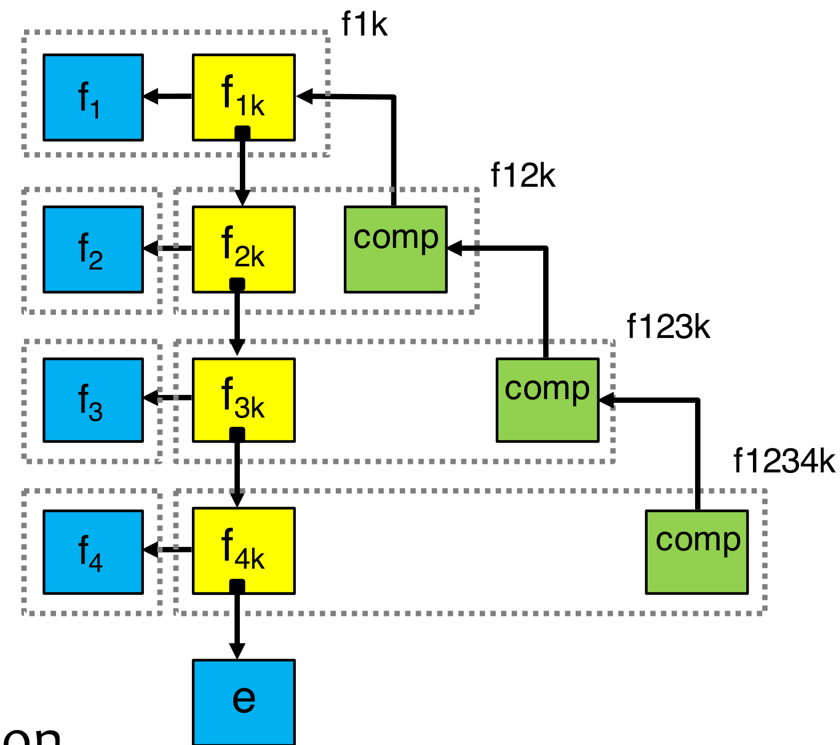
```
function    cps(f) { return function(k) { f(); k() } }

var         f1k = cps(f1);
var        f12k = compose(f1k, f2);
var       f12ck = compose_click(f12k);
var      f12c3k = compose(f12ck, f3);
var     f12c34k = compose(f12c3k, f4);
var    f12c34sk = compose_sleep(f12c34k);
var   f12c34s5k = compose(f12c34sk, f5);
var  f12c34s56k = compose(f12c34s5k, f6);
```



Overview of our approach: The crux is writing the `compose` operator. Once we have it, we'll just trivially wrap it in `.next`. `Compose accepts f1k and f2 and produces comp.`

The actual composition code

```
var        f1k = cps(f1);
var       f12k = compose(  f1k, f2);
// This example omits the click call, for simplicity.
var      f123k = compose( f12k, f3);
var     f1234k = compose(f123k, f4);

function start() { f1234k(e); }
```



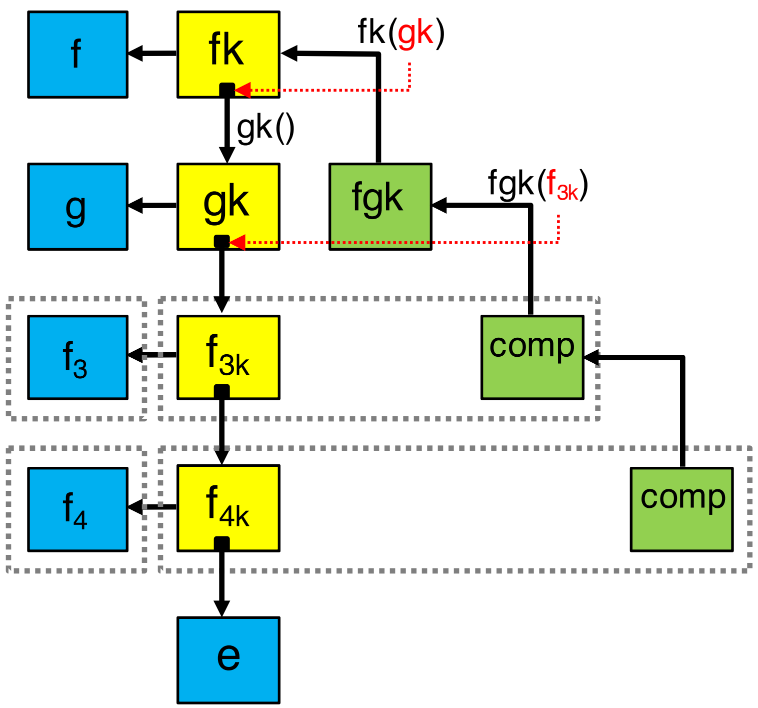
We start the program with the empty continuation e which terminates the execution.

The pattern of the composition is now apparent.

All we need set the continuation calls  . See the next slide.

The composition code (without events)

```
function compose(fk,g)
{
  function fgk(k) {
    function gk() { g(); k(); }
    fk(gk);
  }
  return fgk;
}

var     f1k = cps(f1);
var    f12k = compose(  f1k, f2);
var   f123k = compose( f12k, f3);
var  f1234k = compose(f123k, f4);

f1234k(e);
```



Compose with the click action

```
function compose_click(fk) {
  return function (k) {
    function click_() {
      document.getElementById("myBtn2").onclick = k;
    }
    fk(click_);
  }
}
var         f1k = wrap(f1);
var        f12k = compose(f1k, f2);
var       f12ck = compose_click(f12k);
var      f12c3k = compose(f12ck, f3);
```

5. Final step: wrap it all in methods

```
Function.prototype.click = function() {
        var fk = this;
        return compose_click(fk);
}
Function.prototype.sleep = function() {
        var fk = this;
        return compose_sleep(fk);
}
Function.prototype.next = function(g) {
        var fk = this;
        return compose(fk,g);
}
```

Add begin and .run()

```
        begin
        .next(f1)
        .next(f2)
        .click()
        .next(f3)
        .next(f4)
        .sleep()
        .next(f5)
        .next(f6)
        .run()

var begin = function(k) { k() }   // note that begin == cps(e)

Function.prototype.run = function() {
        var fk = this;
        fk(e);
}
```

Towards full arrowlets

We still need to:

pass events to targets through the "pipeline"

```
EventA("mousedown").bind(start);
```

remove handlers after the event happens

So that the second click does not reexecute f3, f4, …

Hint for the seq puzzle

Problem: Implement function `seq` that allows composition as close as possible to this.

```
// compose the functions
var c = seq(f1)(f2)(f3)(f4)(f5)(f6)()

// run the composition
c()
```

marks the end of composition

CPS Function Arrows

function calls in continuation-passing style

Now let's return to Arrowlets

With the schmarrow language under our belt, we are ready to examime how cps implements the more serious arrowlets language.

We will implement Arrowlets in two steps:

CPS Function Arrows:

- compose functions with a continuation;
- Recall: CPS functions "never" return, always continue

Simple Async Event Arrows

- CPS functions that register their continuations as a handler for the particular event

How is arrowlets different in syntax

Differences from our schmarrow language:

cps functions now take one argument x

- this is in addition to the continuation argument k

Arrowlets uses classes

- .CpsA() and .next(k) rather than cps(f) and compose(k, f)

CPS Function Arrows in JS

Programs we want to write in this section.

```
function f1(x) { return x + 1; }
function f2(x) { print x; }

var f1k = f1.CpsA();   // in schmarrows, this was cps(f1)
var f2k = f2.CpsA();

var comp = f1k.next(f2k);
comp.run(1);    /* prints 2 */
```

Still no events, just functions. But with CPS Arrows in hand, adding events will be trivial.

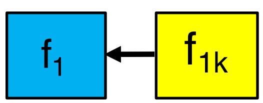
Key idea: CpsA "lifts" the function f into a cps function. next then composes the cps functions.

Step 1: Transform function into cps functions

```
function f1(x) { return x + 1; }
function f2(x) { print x; }

var f1k = f1.CpsA();
var f2k = f2.CpsA();

var comp = f1k.next(f2k);
comp.run(1);    /* prints 2 */
```

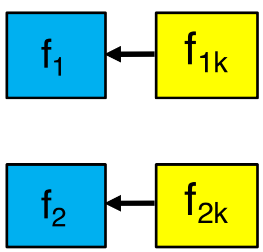
Recall syntax change from

wrap(f) → f.CpsA()



Step 1: Transform function into cps functions

```
function f1(x) { return x + 1; }
function f2(x) { print x; }

var f1k = f1.CpsA();
var f2k = f2.CpsA();

var comp = f1k.next(f2k);
comp.run(1);    /* prints 2 */
```



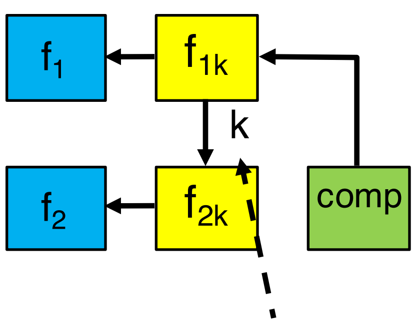
Step 2: Compose continuations

```
function f1(x) { return x + 1; }
function f2(x) { print x; }

var f1k = f1.CpsA();
var f2k = f2.CpsA();

var comp = f1k.next(f2k);
comp.run(1);    /* prints 2 */
```

Recall syntax change from

compose(k1, f2) → k1.next(k2)

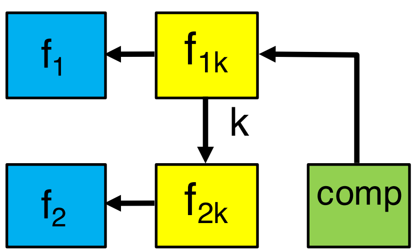
where k2 is CPS version of f2



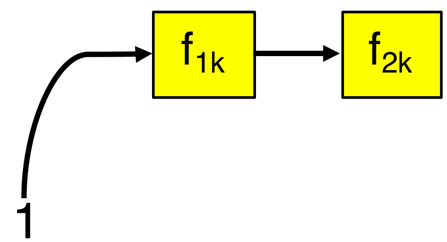
k: the next continuation to call

Step 3: Apply the composed chain to value

```
function f1(x) { return x + 1; }
function f2(x) { print x; }

var f1k = f1.CpsA();
var f2k = f2.CpsA();

var comp = f1k.next(f2k);
comp.run(1);    /* prints 2 */
```



In Arrowlets diagram:



How are `CpsA` and `next` implemented?

Implementation steps

1. Define the CpsA class
2. Add CpsA() method to Function class
   (to turn ordinary Functions into CpsA objects)
3. Define CpsA.run(x)
4. Define CpsA.next(k) to compose two CpsA objects

Step 1: Define the CpsA class

// create a class (prototype) CpsA with a field cps storing the continuation

// Constructor for the CpsA class

```
function CpsA(cps) {      // cps is a function in CPS style, returns void
    this.cps = cps;       // i.e., cps is an function with type (x , k) → ()
                          // can be invoked by  CpsAObj.cps(x,k)
}
```

// CpsA.CpsA() method

// will see why this is useful in the implementation of CpsA.next

```
CpsA.prototype.CpsA = function() { return this ;  }
```

Step 2: Add CpsA() method to the Function class

// convert a direct-style function into a cps function stored in a CpsA object

```
// JS syntax: add method CpsA() to the JS Function class
Function.prototype.CpsA = function() {
    var f = this;
    // wrap the regular (direct-style) function f in a CpsA object
    return new CpsA(function(x, k) {
        k(f(x));            // note: f(x) in k(f(x)) is not a tail call
    });
}
```

x: argument to pass to f

k: the continuation to execute after f(x) returns

When called, we will first call f(x), and then pass the value to k
What is f? It’s the function that we are converting to cps

Step 3: Define CpsA.run(x)

// run calls the CPS function stored in the CpsA object,
// passing it the input argument and an empty continuation.
// The empty continuation will stop the chain of tail calls, ending the
// evaluation

```
CpsA.prototype.run = function(x) {
    this.cps(x, function(y) {});
}
```

Step 4: Define CpsA.next(k) to compose CpsA objs

```
CpsA.prototype.next = function(g) {
    var f = this;
    // if g is a function, then g.CpsA() will convert it into cps
    // but if g already is cps, then g.CpsA() is an identity function
    // (see implementation of CpsA.CpsA() method 3 slides back)
    g = g.CpsA();
    // f and g are now CpsA objects. Now let's create a new function
    // such that when called, it would execute their composition
    var fgComposed =
      function(x, k) {
        f.cps(x, function(y) { g.cps(y, k); })
      };
    // and wraps the composition in a new CpsA object
    var r = new CpsA(fgComposed); return r;
}
```

Example

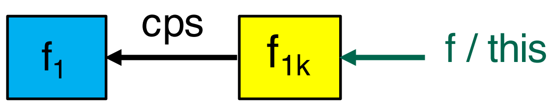
```
function f1(x) { return x + 1; }
function f2(x) { print x; }
var f1k = f1.CpsA();
var f2k = f2.CpsA();

var comp = f1k.next(f2k);
comp.run(1);    /* prints 2 */
```

```
CpsA.prototype.next = function(g) {
    var f = this;
    g = g.CpsA();
    var fgComposed =
        function(x, k) {
          f.cps(x, function(y) {
            g.cps(y, k); })
        };
    var r = new CpsA(fgComposed);
    return r;
}
```

Example

```
function f1(x) { return x + 1; }
function f2(x) { print x; }
var f1k = f1.CpsA();
var f2k = f2.CpsA();

var comp = f1k.next(f2k);
comp.run(1);    /* prints 2 */
```

```
CpsA.prototype.next = function(g) {
    var f = this;
    g = g.CpsA();
    var fgComposed =
        function(x, k) {
          f.cps(x, function(y) {
            g.cps(y, k); })
        };
    var r = new CpsA(fgComposed);
    return r;
}
```



Example

```
function f1(x) { return x + 1; }
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var comp = f1k.next(f2k);
comp.run(1);    /* prints 2 */
```
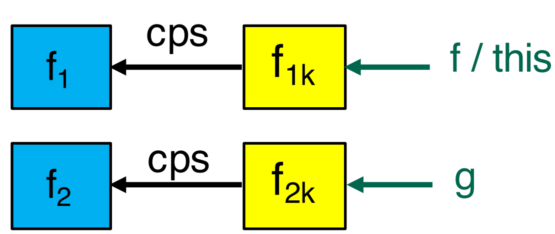

```
CpsA.prototype.next = function(g) {
    var f = this;
    g = g.CpsA();
    var fgComposed =
        function(x, k) {
          f.cps(x, function(y) {
            g.cps(y, k); })
        };
    var r = new CpsA(fgComposed);
    return r;
}
```



Example

```
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```
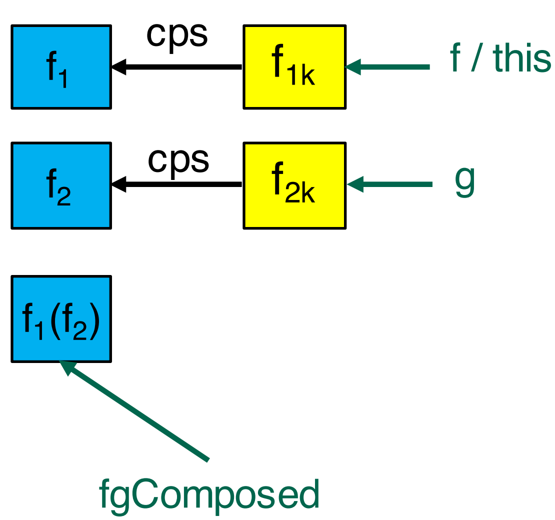
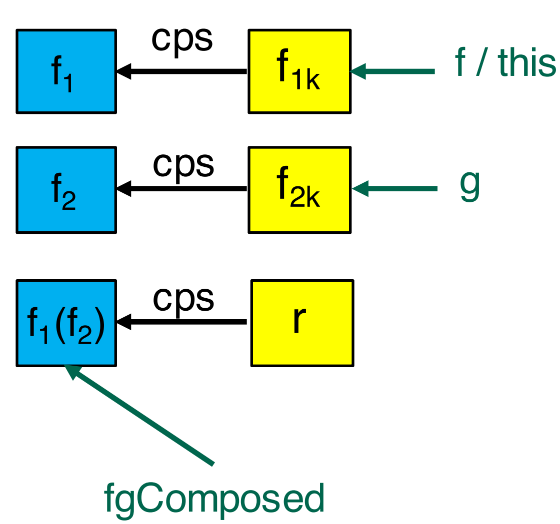

```
CpsA.prototype.next = function(g) {
    var f = this;
    g = g.CpsA();
    var fgComposed =
        function(x, k) {
          f.cps(x, function(y) {
            g.cps(y, k); })
        };
    var r = new CpsA(fgComposed);
    return r;
}
```



Example

```
function f1(x) { return x + 1; }
function f2(x) { print x; }
var f1k = f1.CpsA();
var f2k = f2.CpsA();

var comp = f1k.next(f2k);
comp.run(1);    /* prints 2 */
```

```
CpsA.prototype.next = function(g) {
    var f = this;
    g = g.CpsA();
    var fgComposed =
        function(x, k) {
          f.cps(x, function(y) {
            g.cps(y, k); })
        };
    var r = new CpsA(fgComposed);
    return r;
}
```



Example

```
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var comp = f1k.next(f2k);
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CpsA.prototype.next = function(g) {
    var f = this;
    g = g.CpsA();
    var fgComposed =
        function(x, k) {
          f.cps(x, function(y) {
            g.cps(y, k); })
        };
    var r = new CpsA(fgComposed);
    return r;
}
```
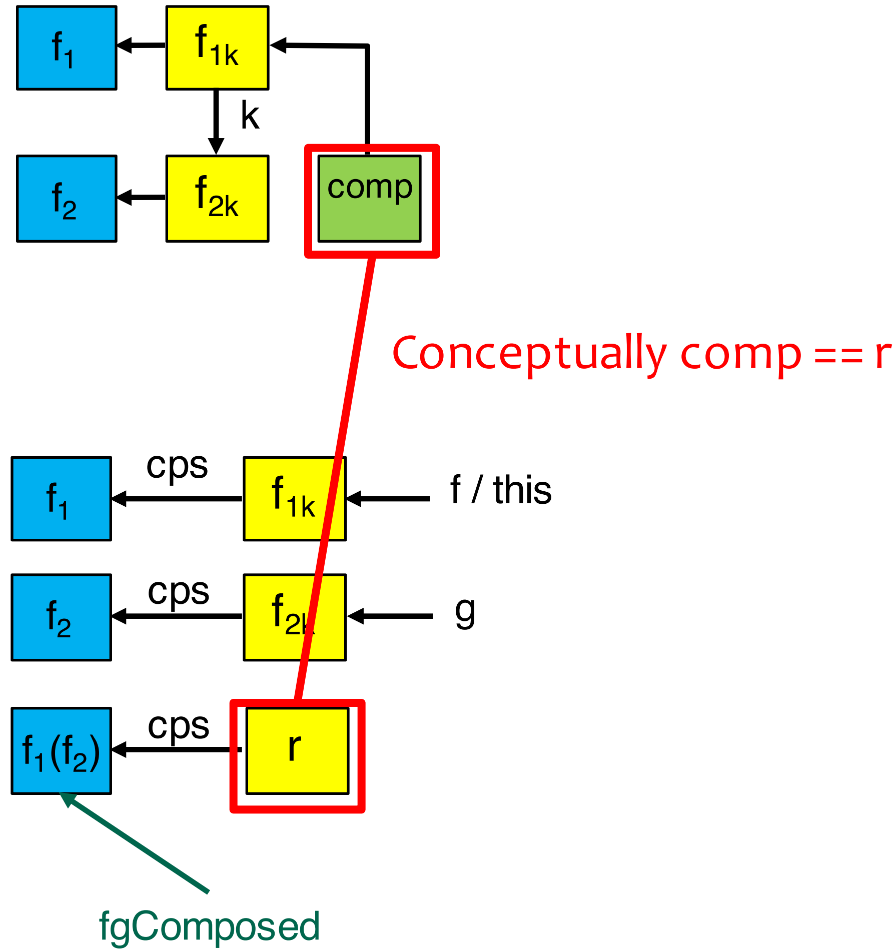



Simple Async Event Arrows

let’s add events

Where are we?

Function Arrows:

- compose direct-style functions

CPS Function Arrows:

- compose continuation-passing-style functions
- CPS functions "never" return, always continue

next, Simple Async Event Arrows

- CPS functions that register their continuations as a handler for the particular event

Example of programs we want to write

```
var count = 0;

// this is a regular handler, nothing special here
function clickTargetA (event) {
    var target = event.currentTarget ;
    target.textContent = "You clicked me! " + ++count;
    return target ;
}

SimpleEventA("click")      // wait for click event
  .next( clickTargetA )    // call handler on target passed to next
  .run(document.getElementById("target")); // select the target
```

Reuse of code is now possible

Same code composition run on a different target

```
SimpleEventA("click")
   .next( clickTargetA )
   .run(document.getElementById(“anotherTarget"));
```

Defining the SimpleEventA class

```
// Class constructor
function SimpleEventA(eventname) {
    if (!(this instanceof SimpleEventA))
        return new SimpleEventA(eventname);
    this.eventname = eventname;
}
```

Explanation:

If the constructor SimpleEventA is called as a regular function (i.e., without new), it calls itself again as a constructor to create a new SimpleEventA object.

This allows us to omit new when using SimpleEventA, for example in `.next( SimpleEventA("click") )`

Making SimpleEventA a “subclass” of CpsA

// First, create a function that will be invoked when the continuation
// associated with SimpleEventA is called, here k is the continuation that will
// be called when the event handler is invoked

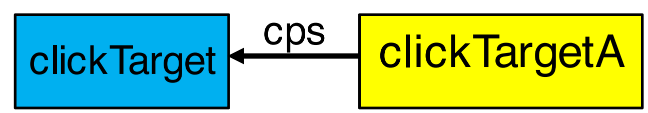
// Next, we make SimpleEventA a subclass of CpsA by setting its prototype
// field to be a CpsA object (JS doesn’t really have inheritance)

```
SimpleEventA.prototype = new CpsA(function(target, k) {
    var f = this;
    // register event handler as part of the continuation
    function handler(event) {
        target.removeEventListener(
            f.eventname, handler, false);
        k(event);
    }
    target.addEventListener(f.eventname, handler, false);
});
```

Example

```
var s = SimpleEventA("click")
        .next( clickTargetA );
        .run(document.getElementById("target"));
```

```
function SimpleEventA(eventname) {
  ...
  this.eventname = eventname;
}
```




```
SimpleEventA.prototype = new CpsA(
  function(target, k) {
    var f = this;
    function handler(event) {
        target.removeEventListener(f.eventname, handler, false);
        k(event);
    }
    target.addEventListener(f.eventname, handler, false);
});
```

Example

```
var s = SimpleEventA("click")
          .next( clickTargetA );
          .run(document.getElementById("target"));
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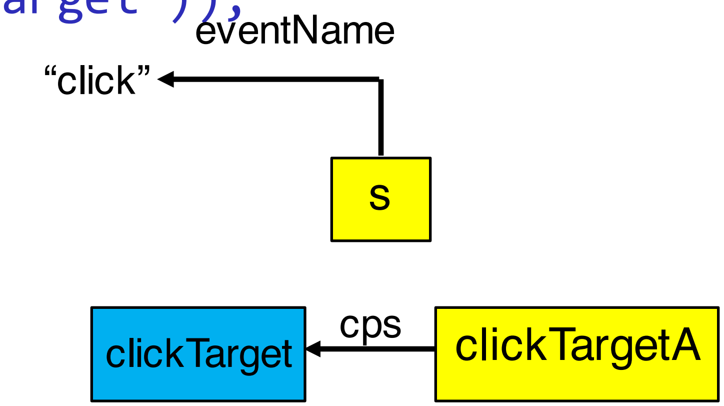


```
function SimpleEventA(eventname) {
  ...
  this.eventname = eventname;
}

SimpleEventA.prototype = new CpsA(
  function(target, k) {
    var f = this;
    function handler(event) {
        target.removeEventListener(f.eventname, handler, false);
        k(event);
    }
    target.addEventListener(f.eventname, handler, false);
});
```

Example

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var s = SimpleEventA("click")
          .next( clickTargetA );
          .run(document.getElementById("target"));
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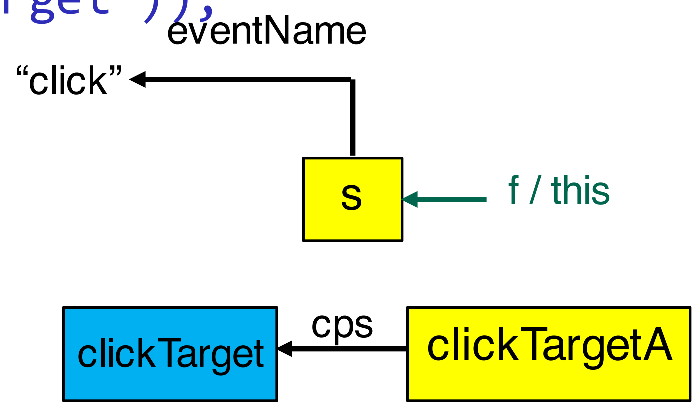


```
function SimpleEventA(eventname) {
  ...
  this.eventname = eventname;
}

SimpleEventA.prototype = new CpsA(
  function(target, k) {
    var f = this;
    function handler(event) {
        target.removeEventListener(f.eventname, handler, false);
        k(event);
    }
    target.addEventListener(f.eventname, handler, false);
});
```

Example

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var s = SimpleEventA("click")
          .next( clickTargetA );
          .run(document.getElementById("target"));
```
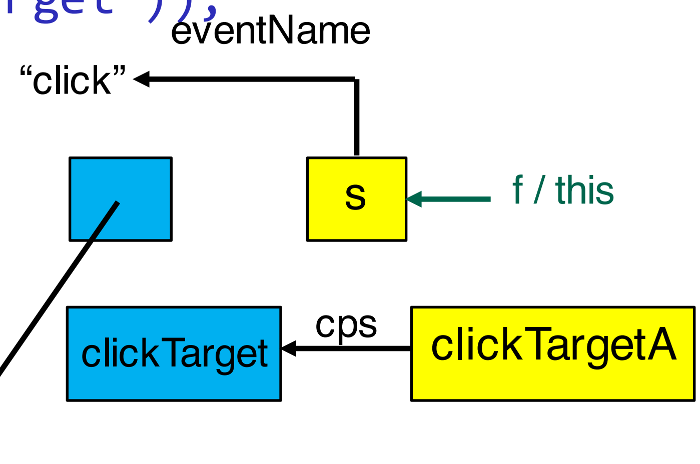
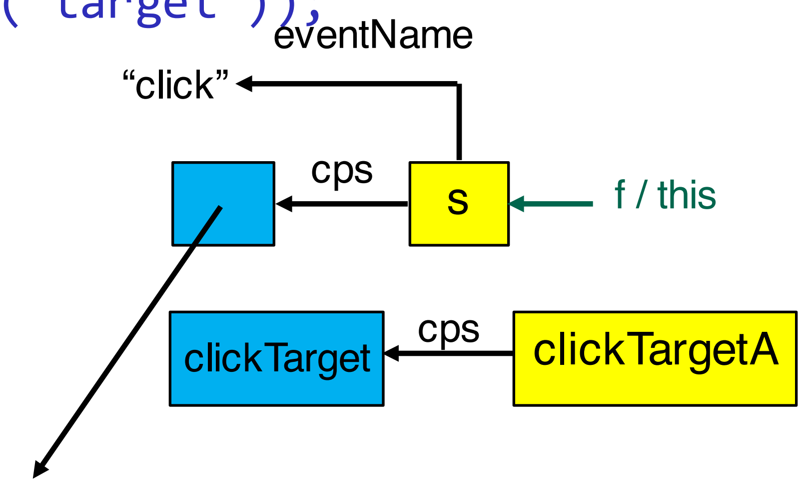




```
function SimpleEventA(eventname) {
  ...
  this.eventname = eventname;
}

SimpleEventA.prototype = new CpsA(
  function(target, k) {
    var f = this;
    function handler(event) {
        target.removeEventListener(f.eventname, handler, false);
        k(event);
    }
    target.addEventListener(f.eventname, handler, false);
});
```

Example

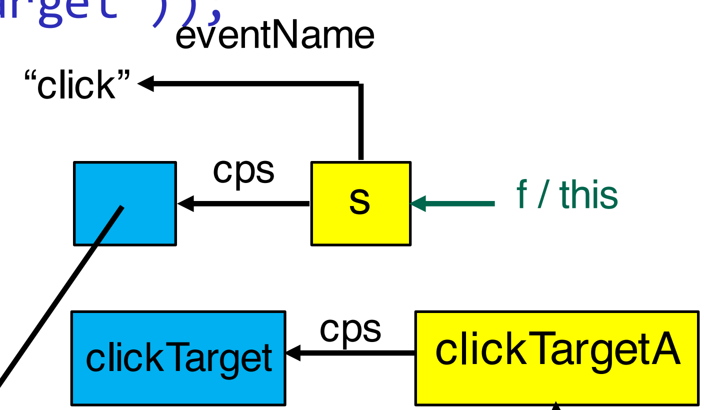
```
var s = SimpleEventA("click")
         .next( clickTargetA );
         .run(document.getElementById("target"));
```




```
function SimpleEventA(eventname) {
  ...
  this.eventname = eventname;
}

SimpleEventA.prototype = new CpsA(
  function(target, k) {
    var f = this;
    function handler(event) {
        target.removeEventListener(f.eventname, handler, false);
        k(event);
    }
    target.addEventListener(f.eventname, handler, false);
});
```

Example

```
var s = SimpleEventA("click")
      .next( clickTargetA );
      .run(document.getElementById("target"));
```




```
function SimpleEventA(eventname) {
  ...
  this.eventname = eventname;
}

SimpleEventA.prototype = new CpsA(
  function(target, k) {
    var f = this;
    function handler(event) {
        target.removeEventListener(f.eventname, handler, false);
        k(event);
    }
    target.addEventListener(f.eventname, handler, false);
});
```

Another example (wait for two clicks)

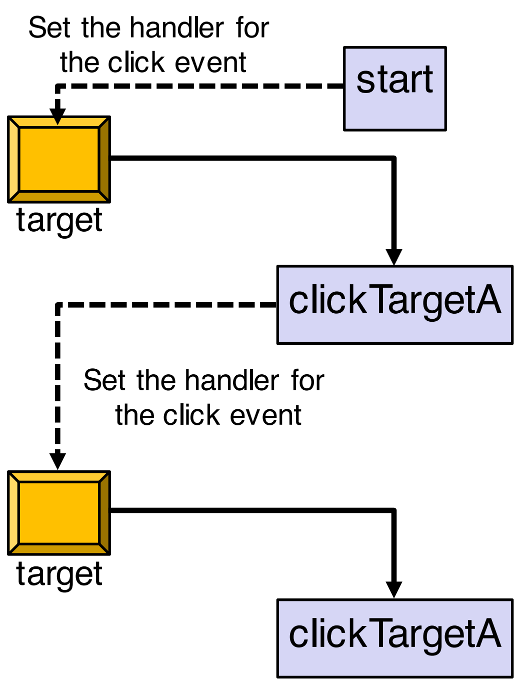
```
SimpleEventA("click")
    .next( clickTargetA )
     // as the next step of the pipeline, wait for click and call handler
    .next( SimpleEventA("click").next( clickTargetA ) )
    .run(document.getElementById("target"))
```

Same as this program (because .next is associative):

```
SimpleEventA("click")
   .next( clickTargetA )
   .next( SimpleEventA("click") )
   .next( clickTargetA )
   .run(document.getElementById("target"));
```

Another example (wait for two clicks)

```
SimpleEventA("click")
    .next( clickTargetA )
     // as the next step of the pipeline, wait for click and call handler
    .next( SimpleEventA("click").next( clickTargetA ) )
    .run(document.getElementById("target"))
```




```
SimpleEventA.prototype = new CpsA(function(target, k)
{
    var f = this;
    function handler(event) {
        target.removeEventListener(
            f.eventname, handler, false);
        k(event);
    }
    target.addEventListener(f.eventname, handler,
                            false);
});
```

Full Async Event Arrows

a realistic system

Full Asynchronous Event Arrows

Function Arrows:

- compose functions in a wrapper function

CPS Function Arrows:

- compose functions with a continuation;
- CPS functions “never” return, always continue

Simple Async Event Arrows

- CPS functions that register their continuations to handle a particular event

next, Full Async Event Arrows

- We will add combinators needed by drag and drop
- see last lecture and the paper for details if interested

Full Async Arrows

Want to support multiple arrows in flight

- i.e., wait for multiple events at once

Only one of the events will happen

- So we must be able to cancel one of the two waiting events

Solution: Build AsyncA,

- – AsyncA extends CpsA to support tracking progress and cancellation
- – When AsyncA is run, it returns a *progress arrow*

Using AsyncA, we build EventA,

- Which extends SimpleEventA to track progress and cancellation.

Example

The next example shows how to perform an animation of bubblesort. We want to sleep for 100ms between each iteration. How to do this nicely in JS?

The Arrowlets code on next slide looks almost like a vanilla bubblesort. The key is the repeat(100) operator that calls the body every 100 ms.

Example

```
var bubblesortA = function(x) {
    var list = x. list , i = x.i , j = x.j ;
    if ( j + 1 < i) {
        if ( list.get( j ) > list.get( j + 1)) {
            list.swap(j, j + 1);
        }
        return Repeat({ list : list, i : i , j : j + 1 });
    } else if ( i>0 ) {
        return Repeat({ list : list , i : i  1, j : 0 });
    } else {
        return Done();
    }
}.AsyncA().repeat(100);
/* list is an object with methods get and swap */
bubblesortA.run({list:list , i : list . length , j : 0 });
```

Summary

- In compiling arrowlet constructs, we introduced the concept of *continuations*
- Continuations represent "the rest of the program"
  - A function that takes in program state and is invoked after the current function terminates
  - Hence it conceptually "never returns" to its caller
- We have seen examples of how this can be used to implement event handlers
- We will see how this is implemented in Rx and Vega in the next lecture

Extra material

How to implement tail recursion elimination when the compiler does not support it

Trampoline

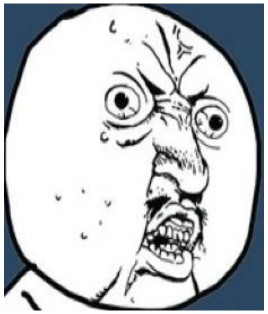
Consider this code in CPS:

```
def f3(x,k) { print x }
def f2(x,k) { k(x+2, { }) }
def f1(x,k) { k(x/2, f3); }
def g(x,k)  { k(x, f2); }

g(1, f1)

{ } = "end" sentinel
```

Call stack:

function	arguments
g	1, f1
f1	1, f2
f2	1/2, f3
f3	1/2 + 2, { }

Stack keeps growing!



Trampoline: Poor man's tail-call optimization

Implement an iterator that keeps executing continuations:

```
trampoline(x, cont) {

 while (cont != { }) {
   (x, cont) = cont(x);
  }

 x
}
```

Now we can write the following:

```
f3(x) { (print x, {}) }
f2(x) { (x+2, f3) }
f1(x) { (x/2, f2) }
g(x)  { (x, f1) }

trampoline(1, g)
```

Call stack:

function	arguments
trampoline	1, g
g	1

Trampoline: Poor man's tail-call optimization

Implement an iterator that keeps executing continuations:

```
trampoline(x, cont) {

 while (cont != { }) {
   (x, cont) = cont(x);
  }

 x
}
```

Now we can write the following:

```
f3(x) { (print x, {}) }
f2(x) { (x+2, f3) }
f1(x) { (x/2, f2) }
g(x)  { (x, f1) }

trampoline(1, g)
```

Call stack:

function	arguments
trampoline	1, g
f1	1/2

Similarly for the rest

Home exercise

Encode our earlier example using trampoline

```
function add1(x) {return x+1;}
function add2(x) {return x+2;}
var add3 = add1.next(add2);
add3(1);
```

```
trampoline(x, cont) {
 while (cont != { }) {
   (x, cont) = cont(x);
  }
 x
}
```

```
def add2(x) { (x+2, {}) }
def add1(x) { (x+1, add2) }
def add3(x) { (x, add1) }
```