Notes for Midterm 2

1 Array Operations

The `.pop()` and `.push(x)` methods remove and add an element from the end of an array:

```
let arr = [10, 20, 30];
arr.push(40);
arr // produces [10, 20, 30, 40]
arr.pop(); // produces 40
arr; // produces [10, 20, 30]
```

The `.shift(x)` and `.unshift()` methods remove and add an element to the beginning of an array:

```
let arr = [10, 20, 30];
arr.unshift(0);
arr // produces [0, 10, 20, 30]
arr.shift(); // produces 0
arr; // produces [10, 20, 30]
```

The `.slice(lo, hi)` method produces a new array with elements starting from `lo` (inclusive) up to `hi` (exclusive): specified range:

```
let arr = [10, 20, 30, 40];
arr.slice(1, 2); // produces [20]
arr.slice(1, 3); // produces [20, 30]
```

You can create a copy of an array using `.slice` as follows:

```
let arr = [10, 20, 30, 40];
let arr2 = arr.slice(0, arr.length); // [10, 20, 30, 40];
arr === arr2; // produces false
```

The `.map(f)` method produces a new array, where the elements are the result of applying `f` to each element of the original array.

```
[10, 20, 30].map(x => x + 1) // [11, 21, 31]
["compsci", "220"].map(x => x.length) // [7, 3]
```

The `.filter(pred)` method produces a new array, which only contains the elements of the original array on which `pred` returns true.

```
[1, 2, 3, 4].filter(x => x % 2 === 0) // [2, 4]
[1, 2, 3, 4].filter(x => x % 2 === 1) // [1, 3]
```

These are examples of `reduce`:

```
[1, 2, 3].reduce((acc, x) => acc + x, 0) // 6
["compsci", "220"].reduce((acc, x) => acc + x.length, 0) // 10
```

It is straightforward to implement these array methods ourselves. Figure 1 implements the higher-order methods as higher-order functions.

2 Singly Linked Lists

A list is either a node (with a head and tail) or the empty list.

```
type List<T> =
  { kind: 'node', head: T,
    tail: List<T> } |
  { kind: 'empty' };
```

```
// map<S, T>(f: (x: S) => T, arr: S[]): T[]
function map(f, arr) {
  let r = [];
  for (let i = 0; i < arr.length; ++i) {
    r.push(f(arr[i]));
  }
  return r;
}

// filter<T>(pred: (x: T) => boolean, arr: T[]): T[]
function filter(pred, arr) {
  let r = [];
  for (let i = 0; i < arr.length; ++i) {
    if (pred(arr[i]) === true) {
    r.push(arr[i]);
  }
  return r;
}

// reduce<S, T>(f: (acc: T, x: S) => T, init: T, arr: S[]): T
function reduce(f, init, arr) {
  let acc = init;
  for (let i = 0; i < arr.length; ++i) {
    acc = f(acc, arr[i]);
  }
  return acc;
}
```

Figure 1: Implementations of higher-order functions over arrays.

These are the list constructors:

```
// node<T>(h: T, t: List<T>): List<T>
function node(h, t) {
  return { kind: node, head: h, tail: t };
}

// empty<T>(): empty<T>
function empty() {
  return { kind: 'empty' };
}
```

An example of a single-linked list:

```
let alist = node(10, node(20, node(30, empty())));
```

Some example functions:

```
// listMap(f: (x: S) => T, alist: List<T>): List<T>
function listMap(f, alist) {
  if (alist.kind === 'empty') {
    return empty();
  } else {
    return node(f(alist.head), listMap(f, alist.tail));
  }
}

// listLength(alist: List<T>): number
function listLength(alist) {
  if (alist.kind === 'empty') {
    return 0;
  } else {
    return 1 + listLength(alist.tail);
  }
}
```

3 Properties of Functions

JavaScript supports *first-class functions*, which have several important properties.

Anonymous Functions First-class functions do not have to be named. A function without a name is known as an anonymous function. For example, the following program immediately applies an anonymous function to an argument:

```
(function(x) { return x + 1; })(10) // produces 11
```

Nested Functions First-class functions can be arbitrarily nested within each other. Moreover, the nested function can read and write to the variables of the enclosing function. For example:

```
// F(x: number): (y: number) => number
function makeAdder(x) {
  function add(y) {
    return x + y; // note that x is not an argument of add
  };
  return add;
}
```

Closures are Values In JavaScript, closures are values. When a function F returns another function G, it is really returning a closure of G, which maps the variables outside of G to their values. For example, we can call the `makeAdder` function defined above twice, which produces two closures of add:

```
let f1 = makeAdder(100); // the value of f1 is add[x -> 100]
let f2 = makeAdder(200); // the value of f2 is add[x -> 200]
```

If we invoke `f1` or `f2`, we run the body of the `add` function, which is `return x + y`. The `add` function receives `y` as an argument, and the value of `x` is taken from the closure. Therefore, we get the following results:

```
f1(10); // produces 110
f2(10); // produces 210
f1(5); // produces 105
```

Delayed Evaluation Functions can be used to *delay evaluation*. For example, the program below does not display anything.

```
// F(g: T): T
function F(g) {
  return g;
}

F(function() { console.log("Will not display"); })
```

This occurs because `F` does not call its argument (i.e., it delays the evaluation of `console.log`), but merely returns it.

The following program actually displays the string, since it calls `g`:

```
// F(g: () => T): T
function F(g) {
  return g();
}
F(function() { console.log("Will display"); })
```

The following program also displays the string, since it calls the result of `F`:

```
// F(g: T): T
function F(g) {
  return g;
}

let r = F(function() { console.log("Will not display"); });
r()
```

Information Hiding In the program below, there is no way to read or modify the value of the parameter x outside the function:

```
// F(x: number): (y: number) => number
function F(x) {
  function g(y) {
    return x + y;
  };
  return g;
}

let f = F(100);
f(10); // produces 110
f.x = 5; // signals an error
```

Similarly, in the program below, there is no way to access the value of the local variable z from outside the function:

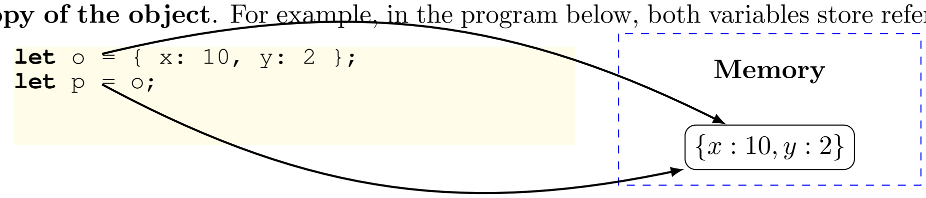
```
// F(x: number): (y: number) => number
function F(x) {
    let z = 9375739 * x;
    function g(y) {
      return y % z;
    };
    return g;
}

let f = F(2003);
console.log(f.z); // signals an error
console.log(f.x); // signals an error, as before
```

Therefore, we say that the closure `g[x -> 2003, z -> 9375739 * 2003]` *hides* the value of z.

4 Object References

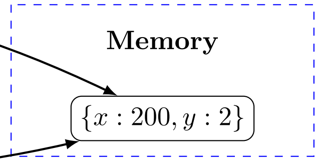
The expression `{`x`:` v`,` y`:` w`, ⋯ }` creates a new object with fields $x, y, \cdots$ in memory and returns a reference to that object. Therefore, variables do not directly store objects. Instead, objects are stored in memory and variables store references to object (i.e., *object referencse*). Therefore, if the variable `o` holds an object reference, then the statement **`let`** `o = p` creates a copy of that reference. It **does not create a copy of the object**. For example, in the program below, both variables store references to the same object:

```
let o = { x: 10, y: 2 };
let p = o;
```



Therefore, updating `p.x` also updates `o.x`, since both refer to the only object in memory:

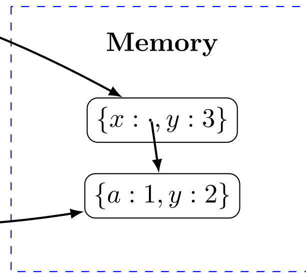
```
let o = { x: 10, y: 2 };
let p = o;
p.x = 200;
console.log(o.x); // displays 200
```



4.1 Nested Objects

The same line of reasoning we used above holds for objects' fields. The following example creates two nested objects. However, the field `o.x` does not hold the object `{a: 1, b: 2 }` itself. Instead, it holds a reference to the object. Therefore, the expression `inner = o.x` stores a copy of the reference in `o.x`.

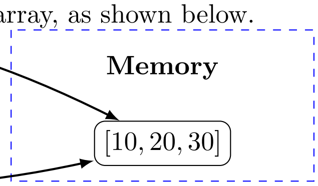
```
let o = {
    x: { a: 1, b: 2 },
    y: 3
};
let inner = o.x;
```



4.2 Arrays

Arrays are similar to objects: the expression `[` a`,` b`,` $\cdots$ `]` creates an array with elements $a, b, \cdots$ in memory and returns a reference to the array. If `arr1` is a variable that holds a reference to an array, then `arr2 = arr1` creates a copy of the reference, and not a copy of the array, as shown below.

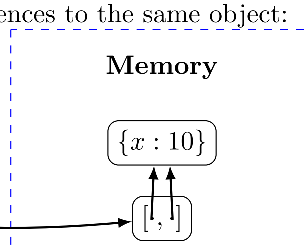
```
let arr1 = [10, 20, 30];
let arr2 = arr1;
```



4.3 Arrays of Objects

The following example creates an array with two references to the same object:

```
let arr = [{ x: 10 }];
arr.push(arr[0]);
```



Therefore, updating the field `x` in via one reference, updates the both references, since they both refer to the same object in memory:

```
arr[0].x = 100;
arr[1].x // produces 100
```

5 Call by Value

When a program calls a function (or method), the method receives *a new copy* of its argument. This is known as *call by value*. For example, consider the following program:

```
function F(x) {
  x = 10;
}

let y = 20;
F(y);
console.log(y); // displays 20
```

`F` receives a copy of the value in `y`. Therefore, when it updates its argument to `10`, the update does not affect the value in `y`.

Call by value is more subtle when working with objects:

```
function G(x) {
  x.m = 20;
}
let y = { m: 10 };
G(y);
console.log(y.m); // displays 20
```

Recall that *objects are not values*, but object references are values. Therefore, `G` receives a copy of the reference to the object `{ m: 10 }` and updates its field `m`. In contrast, the following example updates the value stored in `x` to a reference to a new object:

```
function G(x) {
    x = { m: 20 }
}
let y = { m: 10 };
G(y);
console.log(y.m); // displays 10
```

6 Class Syntax

The two programs below are essentially equivalent:[1]

```
class Point {
  constructor(initX, initY) {
    this.x = initX;
    this.y = initX;
  }
  magnitude() {
    return Math.sqrt(this.x + this.x *
                     this.y + this.y);
  }
}

let p = new Point(3, 4);
p.magnitude()
```

```
function Point(initX, initY) {
  let o = {
    x: initX,
    y: initY,
    magnitude: function() {
      return Math.sqrt(o.x + o.x *
                       o.y + o.y);
    }
  }
  return o;
}

let p = Point(3, 4);
p.magnitude()
```

7 Memoizer

A *memoizer* is an abstraction that wraps a function and "memorizes" its result. Figure 2 shows an implementation of memoizers for a zero-argument function.

In the following example, we use the memoizer to "memorize" the result of `factorial(10)`.

[1] The most significant different is that methods that use **`this`** can exhibit unusual behavior when used as a function. This is a JavaScript-specific detail that is beyond the scope of this class.

```
// type Memo<T> = { get: () => T }
// memo0<T>(f: () => T): Memo<T>
function memo0(f) {
    let r = { kind: ’unknown’ };
    return {
        get: function() {
            if (r.kind === ’unknown’) {
                r = { kind: ’known’, v: f() }
            }
            return r.v;
        },
        toString: function() {
            if (r.kind === ’unknown’) { return ’<unevaluated>’;
            } else { return r.v.toString(); }
        }
    };
}
```

Figure 2: A memoizer for 0-argument functions.

```
function factorial(n) {
    let r = 1;
    while (n > 0) {
        r = r * n;
        n = n - 1;
        console.log("Thinking ...");
    }
    console.log("Done!");
    return r;
}
let f = memo0(() => { return factorial(10); });
f.get();
f.get();
```

Therefore, the program only calls `factorial` *once*, even though it uses the result twice. If we did not call `f.get()`, then factorial would not be called at all.

Memoizers can be used independently, and are a building block for streams.

8 Streams

A *stream* is an abstraction that represents a conceptually unbounded sequence of values. Figure 3 shows an implementation of streams, along with some canonical higher-order functions on streams.

The following stream is the stream of natural numbers $0, 1, 2, 3, \cdots$:

```
// grow(n: number): Stream<number>
function grow(n) {
    return snode(n, memo0(() => grow(n + 1)));
}
let nats = grow(0);
```

Using this stream, we can create streams of even numbers, odd numbers, etc.:

```
let evens = nats.map((n) => n * 2);
let odds = evens.map((n) => n + 1);
```

We can also use `.filter` to create steams of even and odd numbers:

```
let evens = nats.filter((n) => n % 2 === 0);
let odds = nats.filter((n) => n % 2 === 1);
```

```
// sempty: Stream<T>
let sempty = {
    kind: 'sempty',
    map: (f) => sempty,
    filter: (pred) => sempty,
    toString: () => 'sempty'
};

// snode<T>(head: T, tail: Memo: Stream<T>): Stream<T>
function snode(head, tail) {
    return {
        kind: 'snode',
        head: function() { return head; },
        tail: function() { return tail.get(); },
        map: function (f) {
            return snode(f(head), memo0(() => tail.get().map(f)));
        },
        filter: function (pred) {
            if (pred(head)) {
                return snode(head, memo0(() => tail.get().filter(pred)));
            } else {
                return tail.get().filter(pred);
            }
        },
        toString: function() {
            return "snode(" + head.toString() + ", " + tail.toString() + ")";
        }
    }
}
```

Figure 3: Streams, with higher-order functions.

9 Results

The *Result* abstraction is a uniform way to indicate successful and failing computations, without resorting to exceptions or special values (e.g., `NaN` or `null`). Figure 4 shows an implementation of results.

There are two constructors for results:

1. **new** `Success(value)` represents a successful computation that produces the value `value`.

2. **new** `Failure(reason)` represents a failed computation that failed for the given `reason` (usually a string).

Both kinds of results have a `.then`

In the example below, suppose that `F` produces a result, then `G` gets called only if `F` produces a `Success`:

```
F().then(function(x) {
    console.log("F succeeded and produced " + x.toString());
    return G();
});
```

Results can be "chained together". In the example below, if both `F` and `G` produce results, then the final result is `Success` only if they both produce `Success`:

```
F().then(function(x) { return G(x) })
   .then(function(y) {
       console.log("F and G succeeded");
       return new Success(true);
   });
```

```
class Success {
    constructor(value) {
        this.kind = 'success';
        this.value = value;
    }

    then(f) {
        return f(this.value);
    }
}

class Failure {
  constructor(reason) {
    this.kind = 'failure';
    this.reason = reason;
  }

  then(f) {
    return this;
  }
}
```

Figure 4: The Result abstraction.

This page intentionally left blank.

This page intentionally left blank.

This page intentionally left blank.