Notes for Midterm 1

1 First-Order Methods over Arrays

The `.pop` and `.push` 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` 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` method produces a new array with elements in the specified range:

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

Note that the first argument to `.slice` (the lower bound) is inclusive, and the second argument (the upper bound) is exclusive. 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); // produces [10, 20, 30, 40];
arr === arr2; // produces false
```

2 Higher-Order Functions over Arrays

2.1 Map

This is the implementation of `map`:

```
// 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;
}
```

These are examples of `map`:

```
map(function(x) { return x + 1; }, [10, 20, 30]) // produces [11, 21, 31]
map(function(x) { return x.length; }, ["compsci", "220"]) // produces [7, 3]
```

Note that `map` is also a method on arrays:

```
arr.map(f)
```

2.2 Filter

This is the implementation of `filter`:

```
// 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;
}
```

These are examples of `filter`:

```
filter(function(x) { return x % 2 === 0; }, [1, 2, 3, 4]) // produces [2, 4]
filter(function(x) { return x % 2 === 1; }, [1, 2, 3, 4]) // produces [1, 3]
```

Note that filter is also a method on arrays:

```
arr.filter(pred)
```

2.3 Reduce

This is the implementation of `reduce`

```
// 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;
}
```

These are examples of `reduce`:

```
reduce(function(acc, x) { return acc + x; }, 0, [1, 2, 3]) /// produces 6
reduce(function(acc, x) { return acc + x.length; }, 0, ["compsci", "220"]) /// produces 10
```

Note that reduce is also a method on arrays:

```
arr.reduce(f, init)
```

3 Singly Linked Lists

These are the list constructors:

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

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

This function tests a list to check if it is empty:

```
// function isEmpty<T>(list: List<T>): boolean
function isEmpty(list) {
  return list.kind === 'empty';
}
```

These are the list accessors:

```
function head(list) {
  return list.head;
}

function tail(list) {
  Return list.tail;
}
```

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 (isEmpty(alist)) {
    return empty();
  } else {
    return node(f(head(alist)), listMap(f, tail(alist)));
  }
}

// listLength(alist: List<T>): number
function listLength(alist) {
  if (isEmpty(alist)) {
    return 0;
  } else {
    return 1 + listLength(tail(alist));
  }
}
```

4 Key Properties of First-Class Functions

4.1 Anonymous Functions

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

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

4.2 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 y is not a parameter of this function
  };
  return add;
}
```

4.3 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
```

4.4 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()
```

4.5 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) {
```

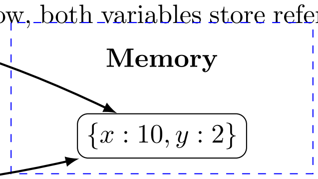
```
        return y % z;
    };
    return g;
}

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`.

5 Object References

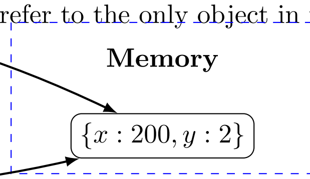
The expression `{`x`: `v`, `y`: `w`, `$\cdots$` }` creates a new object with fields $x, y, \cdots$ in memory and returns a reference to that object. Therefore, variables do not directly store objects. Instead, objects are stored in memory and variables store references to object (i.e., *object referencse*). 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:

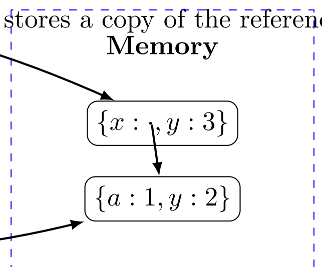
```
let o = { x: 10, y: 2 };
let p = o;
p.x = 200;
console.log(o.x); // displays 200
```



5.1 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`.

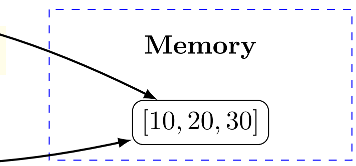
```
let o = {
    x: { a: 1, b: 2 },
    y: 3
};
let inner = o.x;
```



5.2 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.

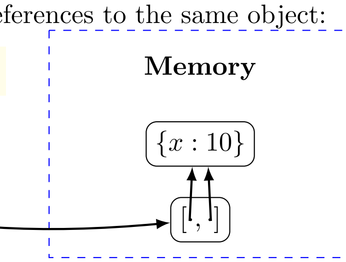
```
let arr1 = [10, 20, 30];
let arr2 = arr1;
```



5.3 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
```

This page intentionally left blank.

This page intentionally left blank.

This page intentionally left blank.