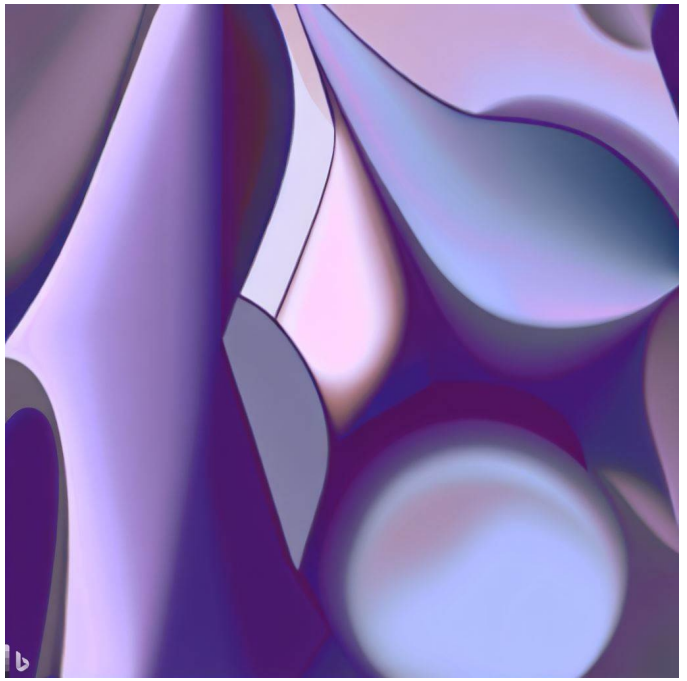

CSE 331

Data Abstraction

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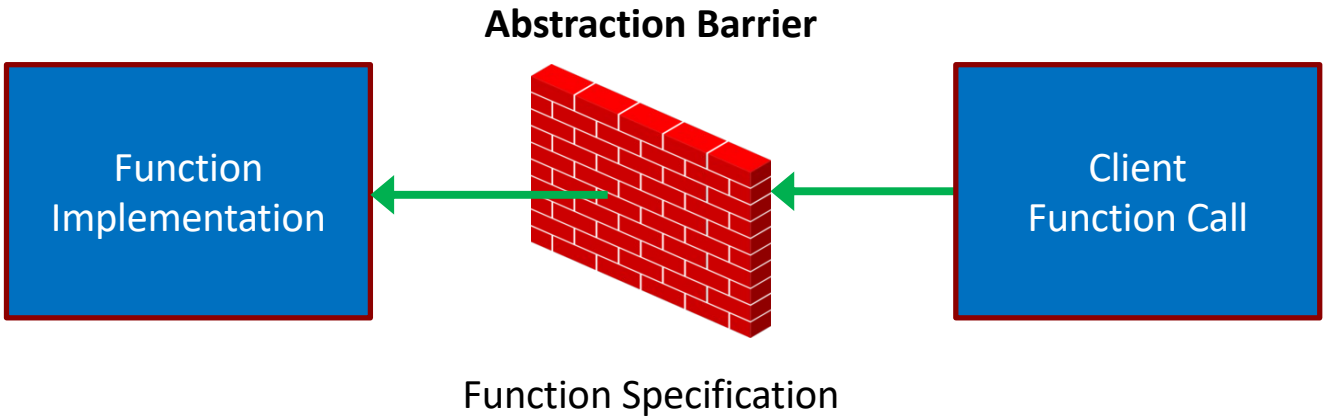
Abstraction Barrier

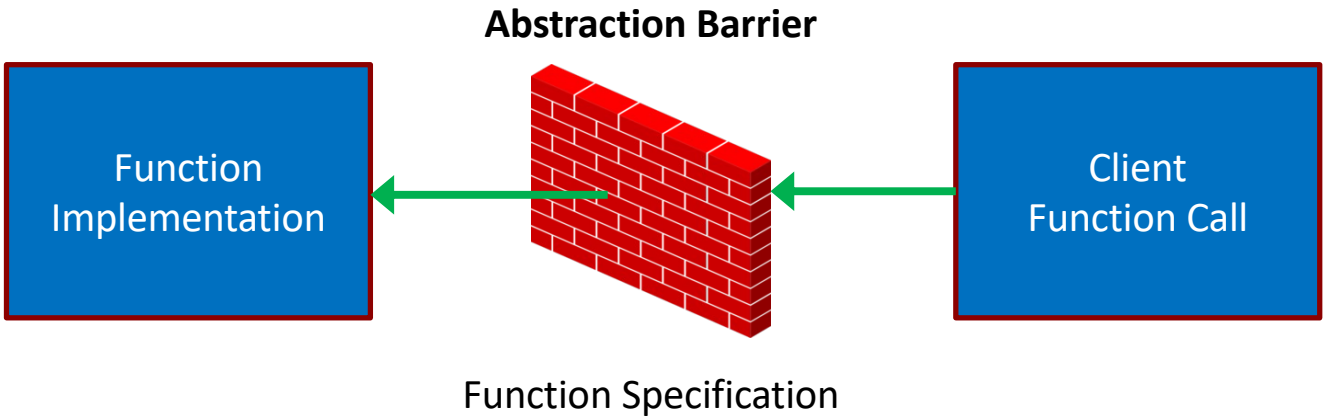
- Last time, we saw *procedural* abstraction



  - specification is the "barrier" between the sides
  - clients depend only on the spec
  - implementer can write any code that satisfies the spec

Abstraction Barrier

- Last time, we saw *procedural* abstraction



- Specifications improve
  - understandability (client)
  - changeability (implementation)
  - modularity

correctness is impossible without specifications

Performance Improvements

- Last time, we saw `rev-acc`, which is faster than `rev`
  - faster *algorithm* for reversing a list
  - rare to see this
- Most perf improvements change ***data structures***
  - different kind of abstraction barrier for data
- Let's see an example...

Last Element of a List

func last(nil) := undefined

last(cons(x, nil)) := x for any x : $\mathbb{Z}$

last(cons(x, cons(y, L)) := last(cons(y, L)) for any x, y : $\mathbb{Z}$ and any L : List

- Runs in $\Theta(n)$ time
  - walks down to the end of the list
  - no faster way to do this on a list

- We could cache the last element
  - new data type just dropped:

```
type FastLastList = {list: List, last: number|undefined}
```

empty list has undefined last

Fast-Last List

```
type FastLastList = {list: List, last: number|undefined}
```

- **How do we switch to this type?**
  - **change every** `List` **into** `FastLastList`
- **Will still have functions that operate on List**
  - **e.g.,** len, sum, concat, rev
- **Suppose** `F` **is a** `FastLastList`
  - **instead of calling** `rev(F)`**, we have call** `rev(F.list)`
  - **cleaner to introduce a helper function**

Fast-Last List

```
type FastLastList = {list: List, last: number|undefined}

const getLast = (F: FastLastList): number|undefined => {
  return F.last;
};

const toList = (F: FastLastList): List<number> => {
  return F.list;
};
```

- How do we switch to this type?
  - change every `List` into `FastLastList`
  - replace `F` with `toList(F)` where a `List` is expected
- What happens if we need to change it again?
  - do it all over again!

Another Fast List

- **Suppose we often need the 2nd to last, 3rd to last, ... (back of the list). How can we make it faster?**
  - **store the list in *reverse* order!**

```
type FastBackList = List<number>;

const getLast = (F: FastBackList): number|undefined => {
  return (F === nil) ? undefined : F.hd;
};

const getSecondToLast = (F: FastBackList): number|undefined => {
  return (F === nil) ? undefined :
         (F.tl === nil) ? undefined : F.tl.hd;
};

const toList = (F: FastBackList): List<number> => {
  return rev(F);
};
```

Another Fast List

```
type FastBackList = List<number>;

const getLast = (F: FastBackList): number|undefined => {
  return (F === nil) ? undefined : F.hd;
};

const toList = (F: FastBackList): List<number> => {
  return rev(F);
};
```

- **Problems with this solution...**
  - **no type errors if someone forgets to call `toList`!**

```
const F: FastBackList = …;
return concat(F, cons(1, nil));  // bad!
```

Another Fast List — Take Two

```
type FastBackList = {list: List<number>};

const getLast = (F: FastBackList): number|undefined => {
  return (F.list === nil) ? undefined : F.list.hd;
};

const toList = (F: FastBackList): List<number> => {
  return rev(F.list);
};
```

- Still some problems...
  - no type errors if someone grabs the field directly

```
const F: FastBackList = …;
return concat(F.list, cons(1, nil));  // bad!
```

Another Fast List — Take Three

```
const F: FastBackList = …;
return concat(F.list, cons(1, nil));  // bad!
```

- Only way to completely stop this is to hide `F.list`
  - do not give them the data, just the functions

```
type FastList = {
  getLast: () => number|undefined,
  toList: () => List<number>
};
```

  - the only way to get the list is to call `F.toList()`
  - seems weird… but we can make it look familiar

Another Fast List — Take Three

```
interface FastList {
  getLast: () => number|undefined;
  toList: () => List<number>;
}
```

- In TypeScript, “interface” is synonym for “record type”
- You’ve seen this in Java

Java interface is a record where field values are functions (methods)

```
interface FastList {
  int getLast() throws EmptyList;
  List<Integer> toList();
}
```

  - in 331, our interfaces will only include functions (methods)

Data Abstraction

Data Abstraction

- Give clients only operations, not data
  - operations are “public”, data is “private”
- We call this an Abstract Data Type (ADT)
  - invented by Barbara Liskov in the 1970s
  - fundamental concept in computer science

    built into Java, JavaScript, etc.
  - data abstraction via procedural abstraction

- Critical for the properties we want
  - easier to change data structure
  - easier to understand (hides details)
  - more modular

How to Make a `FastList` — Attempt One

```
const makeFastList = (list: List<number>): FastList => {
  const last = last(list);
  return {
    getLast: () => { return last; },
    toList: () => { return list; }
  };
};
```

- Values in `getLast` and `toList` fields are functions
- There is a cleaner way to do this
  - will also look more familiar

How to Make a `FastList`

```
class FastLastList implements FastList {
  last: number|undefined;  // should be "readonly"
  list: List<number>;

  constructor(list: List<number>) {
    this.last = last(list);
    this.list = list;
  }

  getLast = () => { return this.last; };
  toList = () => { return this.list; };
}
```

- Can create a new record using "`new`"
  - each record has fields `list`, `last`, `getLast`, `toList`
  - bodies of functions use "`this`" to refer to the record

How to Make a `FastList`

```
class FastLastList implements FastList {
  last: number|undefined;  // should be "readonly"
  list: List<number>;

  constructor(list: List<number>) {
    this.last = last(list);
    this.list = list;
  }

  getLast = () => { return this.last; };
  toList = () => { return this.list; };
}
```

- Can create a new record using "`new`"
  - all four assignments are executed on each call to "`new`"
  - `getLast` and `toList` are always the same functions

How to Make a `FastList`

```
class FastLastList implements FastList {
  last: number|undefined;  // should be "readonly"
  list: List<number>;

  constructor(list: List<number>) {
    this.last = last(list);
    this.list = list;
  }

  getLast = () => { return this.last; };
  toList = () => { return this.list; };
}
```

- **Implements the `FastList` interface**
  - **i.e., it has the expected `getLast` and `toList` fields**
  - **(okay for records to have more fields than required)**

Another Way to Make a `FastList`

```
class FastBackList implements FastList {
  list: List<number>;  // stored in reverse order

  constructor(list: List<number>) {
    this.list = rev(list);
  }

  getLast = () => {
    return (this.list === nil) ?
        undefined : this.list.hd;
  };

  toList = () => { return rev(this.list); }
}
```

- **Might be better if we had more operations**
  - `secondToLast`, `thirdToLast`, **etc.**, `rev` **(no op)**

How Do Clients Get a `FastList`

```
const makeFastList = (list: List<number>): FastList => {
  return new FastLastList (list);
};
```

- **Export only `FastList` and `makeFastList`**
  - **completely hides the data representation from clients**

- **This is called a "factory function"**
  - **another design pattern**
  - **can change implementations easily in the future**

    becomes `FastBackList` with a one-line change

- **Difficult to add to the list with this interface**
  - **requires three calls: `toList`, `cons`, `makeFastList`**

Another Way To Do It

```
interface FastList {
  cons: (x: number) => FastList;
  getLast: () => number|undefined;
  toList: () => List<number>;
};

const makeFastList = (): FastList => {
  return new FastBackList(nil);
};
```

- **New method `cons` returns list with `x` in front**
  - **example of a "producer" method (others are "observers")**
    produces a new list for you
  - **now, we only need to make an empty `FastList`**
    anything else can be built via `cons`

Another Way To Do It (Even Better)

```
interface FastList {
  cons: (x: number) => FastList;
  getLast: () => number|undefined;
  toList: () => List<number>;
};

const nilList: FastList = new FastBackList(nil);

const makeFastList = (): FastList => {
  return nilList;
};
```

- No need to create a new object using "`new`" *every time*
  - can reuse the same instance

    only possible since these are immutable!
  - example of the "singleton" **design pattern**

Full ADT Design Pattern for 331

We will use the following design pattern for ADTs:

- "`interface`" used for defining ADTs
  - declares the methods available
- "`class`" used for implementing ADTs
  - defines the fields and methods
  - implements the ADT interface above
- Factory function used to create instances

Stick to regular functions for rest of the code!

Specifications for ADTs

Specifications for ADTs

- **Run into problems when we try to write specs**
  - **for example, what goes after `@return`?**

    don't want to say returns the `.list` field (or reverse of that)

    we want to hide those details from clients

```
interface FastList {
  /**
   * Returns the "underlying" list of items
   * @return ??
   */
  toList: () => List<number>;
};
```

- **Need some terminology to clear up confusion**

ADT Terminology

New terminology for specifying ADTs

Concrete State / Representation (Code)

actual fields of the record and the data stored in them

Last example: `{list: List, last: number|undefined}`

Abstract State / Representation (Math)

how clients should *think* about the object

Last example: List (i.e., nil or cons)

- **We've had different abstract and concrete types all along!**
  - **in our math, List is an inductive type (abstract)**
  - **in our code, `List` is a string or a record (concrete)**

List Is Like an ADT

Inductive types also differ in abstract / concrete states:

Concrete State / Representation (Code)

actual fields of the record and the data stored in them

Last example: `"nil" | {kind: "cons", hd: number, tl: List}`

Abstract State / Representation (Math)

how clients should *think* about the object

Last example: List (i.e., nil or cons)

- **Inductive types also use a design pattern to work in TypeScript**
  - **details are different than ADTs (e.g., no interfaces)**

ADT Terminology

New terminology for specifying ADTs

Concrete State / Representation (Code)

actual fields of the record and the data stored in them

Last example: `{list: List, last: number|undefined}`

Abstract State / Representation (Math)

how clients should *think* about the object

Last example: List (i.e., nil or cons)

- Term "object" (or "obj") will refer to abstract state
  - "object" means mathematical object
  - "obj" is the mathematical value that the record represents

Specifying FastList

```
/**
 * A list of integers that can retrieve the last
 * element in O(1) time.
 */
export interface FastList {
  /**
   * Returns the last element of the list (O(1) time).
   * @returns last(obj)
   */
  getLast: () => number | undefined;
```

- "obj" refers to the abstract state (the list, in this case)
  - actual state will be a record with fields `last` and `list`

Specifying FastList

```
/**
 * A list of integers that can retrieve the last
 * element in O(1) time.
 */
export interface FastList {
  …
  /**
   * Returns the object as a regular list of items.
   * @returns obj
   */
 toList: () => List<number>;
```

- In math, this function does nothing ("`@returns obj`")
  - two *different* concrete representations of the same idea
  - details of the representations are ***hidden*** from clients

Specifying FastList

```
/**
 * A list of integers that can retrieve the last
 * element in O(1) time.
 */
export interface FastList {
  …
  /**
   * Returns a new list with x in front of this list.
   * @returns cons(x, obj)
   */
  cons = (x: number) => FastList;
```

- **Producer method: makes a new list for you**
  - "obj" **above is a list, so** cons(x, obj) **makes sense in math**

Specifying FastList

```
/**
 * A list of integers that can retrieve the last
 * element in O(1) time.
 */
export interface FastList {
  …
  /**
   * Returns a new list with x in front of this list.
   * @returns cons(x, obj)
   */
  cons = (x: number) => FastList;
```

- Specification does not talk about fields, just "obj"
  - fields are ***hidden*** from clients