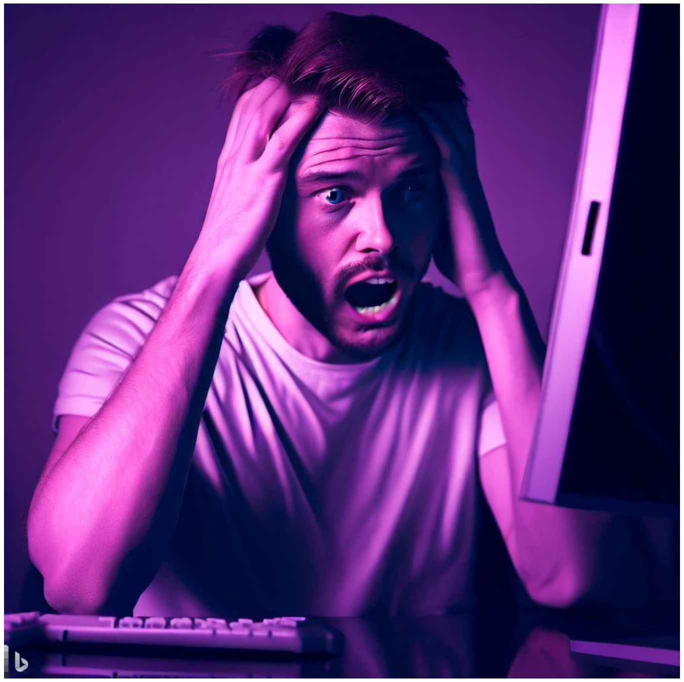


CSE 331

Mutable Heap State

James Wilcox & Kevin Zatloukal

Revisiting HW5

- In HW5, color information in a `ColorInfo` record
  - we used a triple, but a record also works

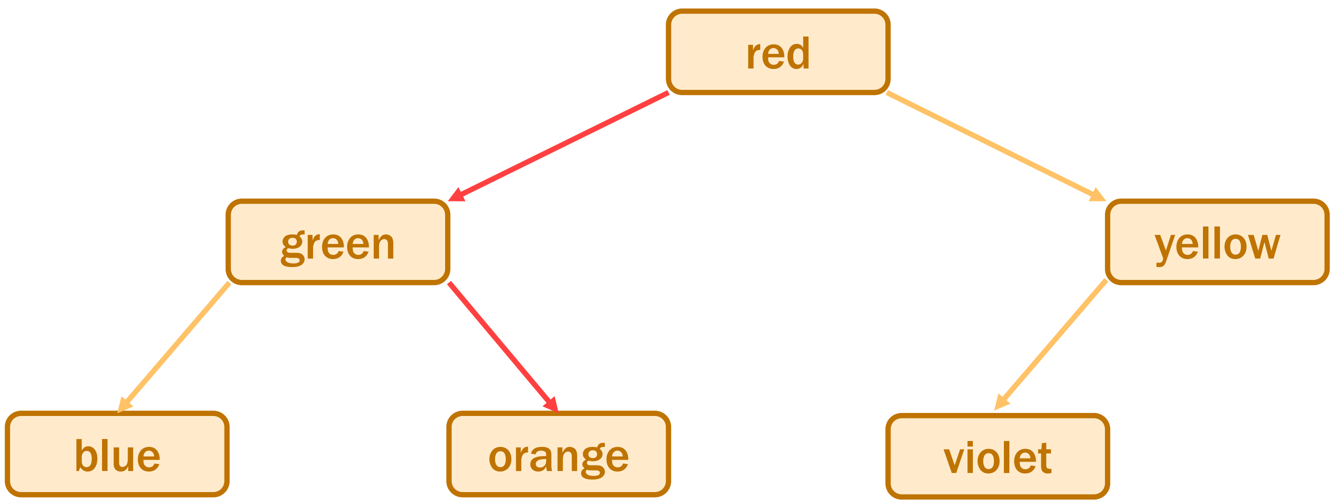
```
type ColorInfo = {
    name: string, cssColor: string, dark: boolean};
```

- Could also write functions that mutate them:

```
const makeFavColor = (c: ColorInfo): ColorInfo => {
  c.name = "pink";
  c.cssColor = "#FFC0CB";
  c.dark = false;
  return c;
};
```

Revisiting HW5

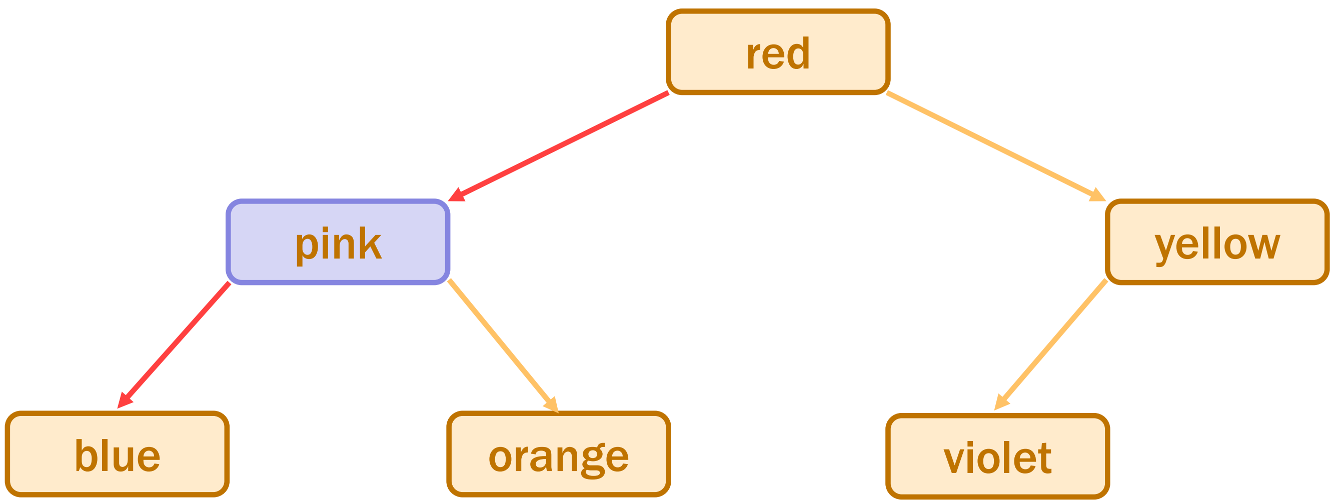
- In HW5, we had a BST of `ColorInfo` records
  - faster way to look up color information
  - e.g., find **orange** like this



- Suppose we called `makeFavColor` on the green record…

Revisiting HW5

- **Suppose we called `makeFavColor` on green record...**
  - **it is mutated into pink**
  - **now this happens when we look for <u>orange</u>:**



  - **it can no longer be found!**

    we violated the BST invariant

Revisiting HW5

- In HW5, color information in a `ColorInfo` record
  – we used a triple, but a record also works

```
type ColorInfo = {
    name: string, cssColor: string, dark: boolean};
```

- Could also write functions that mutate them:

```
const makeFavColor = (c: ColorInfo): ColorInfo => {
  c.name = "pink";
  c.cssColor = "#FFC0CB";
  c.dark = false;
  return c;
};
```

Scary Bugs

- <u>Do not</u> fear crashes
  - those are easy to spot and fix

    get a stack trace that tells you exactly where it went wrong

- <u>Do</u> fear unexpected mutation
  - failure will give you no clue what went wrong

    will take a long time to realize the BST invariant was violated by mutation
  - bug could be almost anywhere in the code

    anyone who mutates a `ColorInfo` could have caused it
  - could take *weeks* to track it down

Correctness Levels

Description	Testing	Tools	Reasoning
small # of inputs	exhaustive		
straight from spec	heuristics	type checking	code reviews
no mutation	“	libraries	calculation induction
local variable mutation	“	“	Floyd logic
array mutation	“	“	for-any facts
heap state mutation	“	“	alias tracking rep invariants

Heap State

- “Heap state” = lives on after the call stack finishes
  - after current function and those calling it all return
  - state could be arrays or records
- No different from before when immutable
  - we don’t care when the garbage collectors gets rid of it
- Vastly more complex when **mutable**…

Mutable Heap State

- “With great power, comes great responsibility”
- With arrays:
  - gain the ability to easily access any element
  - must keep track of information about the whole array
- Additional references to the same object are “aliases”
- With mutable heap state:
  - gain efficiency in some cases
  - must keep track of every alias that could mutate that state

    any alias, anywhere in the *entire* program could cause a bug

Easy Ways to Stay Safe

1. Do not use <u>mutable</u> state
   - don't need to think about aliasing at all
   - any number of aliases is fine

2. Do not allow aliases…
   - create the state in your constructor and **don't share** it

```
class MyClass {
  vals: Array<string>;

  constructor() {
    this.vals = new Array(0);  // only alias
  }
  …
```

Easy Ways to Stay Safe

2. Do not allow aliases

(a) do not hand out aliases yourself

– return copies instead

```
class MyClass {
  // RI: vals is sorted
  vals: Array<string>;

  …

  values: (): Array<string> => {
    return this.vals;                    // unsafe!
    return this.vals.slice(0);  // make a copy
  };

  …
```

Easy Ways to Stay Safe

2. Do not allow aliases

(b) make a copy of anything you want to keep

– does not matter if the caller mutates the original

```
class MyClass {
  // RI: vals is sorted
  vals: Array<string>;
  …
  // @requires A is sorted
  constructor(A: Array<string>) {
    this.vals = A;           // unsafe!
    this.vals = A.slice(0);  // make a copy
  };
  …
```

Easy Ways to Stay Safe

1. Do not use mutable state
   – don't need to think about aliasing at all
   – any number of aliases is fine

2. Do not allow aliases
   a) do not hand out aliases yourself
   b) make a copy of anything you want to keep

ensures only <u>one</u> reference to the object (no aliases)

- For 331, allowing aliases is a <u>bug!</u> ("rep exposure")
  – gives the client the ability to break your code
  – we will stick to these simple strategies for avoiding it

An Advanced (Two-Stage) Approach

- Mutable object has only one reference (owner)
  - one reference that is allowed to use & mutate it
- Object is eventually "frozen", making it immutable
  - no longer necessary to track ownership
- Example: Java's `StringBuilder` vs `String`
  - `StringBuilder` is mutable (be careful!)
  - `StringBuilder.toString` returns the value as a `String`
  - `String` is immutable

Language Features & Aliasing

- Most recent languages have some answer to this…
- Java chose to make `String` immutable
  - most keys in maps are strings
  - hugely controversial at the time, but great decision
- Python chose to only allow immutable keys in maps
  - only numbers, strings, and tuples allowed
  - surprisingly, not that inconvenient
- Rust has built-in support for tracking ownership
  - ownership can be "borrowed" and returned
  - type system ensures there is only one usable alias

Mutable ADTs

ADTs

- Main place we have heap state is in an ADT
- Previously:
  - state was immutable
  - set in the constructor and then never changed

    only need to confirm RI holds at the end of the constructor

    if RI holds there, then it holds forever
- Now:
  - allow state to be changed by methods

ADTs

- Main place we have heap state is in an ADT
- New Power:
  - allow state to be changed by methods
- New Responsibilities:
  - more complex specifications

    add `@effects` and `@modifies`
  - must check the RI holds after any method that mutates

    often a good idea to write code to check this at runtime
  - must avoid aliasing of anything mutable

    we call this “representation exposure”

Recall: List ADT with a Fast `getLast`

```
// Represents an (immutable) list of numbers.
interface FastList {

  // @returns cons(x, obj)
  cons: (x: bigint) => FastList;

  // @returns last(obj)
  getLast: () => bigint|undefined;

  // @returns obj
  toList: () => List<bigint>;
};

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

producer method

Mutable List ADT with a Fast `getLast`

```
// Represents a mutable list of numbers.
interface MutableFastList {

  // @modifies obj
  // @effects obj = cons(x, obj_0)
  cons: (x: bigint) => void;

  …
```

mutator method

- Method `cons` changes the list, putting `x` in front
  - now returns `void`
  - mutation explained in `@modifies` and `@effects`

    abstract state is the old abstract state with x put in front

Mutable List ADT with a Fast `getLast`

```
// Represents a mutable list of numbers.
interface MutableFastList {

  // @modifies obj
  // @effects obj = cons(x, obj_0)
  cons: (x: bigint) => void;
  …
```

mutator method

- **Method `cons` changes the list, putting `x` in front**
  - **now a mutable data type**

    clients need to worry about aliasing
  - **don't make a tree of these!**

Recall: One Concrete Rep for `FastList`

```
class FastListImpl implements FastList {
  // RI: this.last = last(this.list)
  // AF: obj = this.list
  readonly last: bigint | undefined;
  readonly list: List<bigint>;

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

- We can use the same rep for a mutable version

Mutable List ADT with a Fast `getLast`

```
class MutableFastListImpl implements MutableFastList {
  // RI: this.last = last(this.list)
  // AF: obj = this.list
  last: bigint | undefined;
  list: List<bigint>;

  // @modifies obj
  // @effects obj = cons(x, obj_0)
  cons = (x: bigint): void => {
    this.list = cons(x, this.list);
  };
```

- **Let's check correctness…**

Mutable List ADT with a Fast `getLast`

```
class MutableFastListImpl implements MutableFastList {
  // RI: this.last = last(this.list)
  // AF: obj = this.list
  last: bigint | undefined;
  list: List<bigint>;

  // @modifies obj
  // @effects obj = cons(x, obj_0)
  cons = (x: bigint): void => {
    this.list = cons(x, this.list);
    {{ this.list = cons(x, this.list_0) }}
    {{ Post: obj = cons(x, obj_0) }}
  };
```

Mutable List ADT with a Fast `getLast`

```
class MutableFastListImpl implements MutableFastList {
  // RI: this.last = last(this.list)
  // AF: obj = this.list
  last: bigint | undefined;
  list: List<bigint>;

  // @modifies obj
  // @effects obj = cons(x, obj_0)
  cons = (x: bigint): void => {
    this.list = cons(x, this.list);
    {{ this.list = cons(x, this.list_0) }}
    {{ Post: obj = cons(x, obj_0) }}
  };
```

What is missing?

Also, need the RI to hold!

obj	$= \text{this.list}$	**by AF**
	$= \text{cons}(x, \text{this.list}_0)$	**since** $\text{this.list} = \text{cons}(x, \text{this.list}_0)$
	$= \text{cons}(x, \text{obj}_0)$	**by AF**

Mutable List ADT with a Fast `getLast`

```
class MutableFastListImpl implements MutableFastList {
  // RI: this.last = last(this.list)
  // AF: obj = this.list
  last: bigint | undefined;
  list: List<bigint>;

  // @modifies obj
  // @effects obj = cons(x, obj_0)
  cons = (x: bigint): void => {
    this.list = cons(x, this.list);
    {{ this.list = cons(x, this.list_0) }}
    {{ Post: obj = cons(x, obj_0) and
             this.last = last(this.list) }}
  };
```

Also, need the RI to hold!

Does it? No!

- Postcondition is `@returns`, `@effects`, and <u>RI</u>

Mutable List ADT with a Fast `getLast`

```
class MutableFastListImpl implements MutableFastList {
  // RI: this.last = last(this.list)
  // AF: obj = this.list
  last: bigint | undefined;
  list: List<bigint>;

  // @modifies obj
  // @effects obj = cons(x, obj_0)
  cons = (x: bigint): void => {
    this.list = cons(x, this.list);
    this.last = last(this.list);
    {{ this.list = cons(x, this.list₀) and this.last = last(this.list) }}
    {{ Post: obj = cons(x, obj₀) and this.last = last(this.list) }}
  };
```

Rep Invariant now holds

Mutable List ADT with a Fast `getLast`

```
class MutableFastListImpl implements MutableFastList {
  // RI: this.last = last(this.list)
  // AF: obj = this.list
  last: bigint | undefined;
  list: List<bigint>;

  // @modifies obj
  // @effects obj = cons(x, obj_0)
  cons = (x: bigint): void => {
    this.last = last(this.list);
```

{{ **this.last = last(this.list)** }}

```
    this.list = cons(x, this.list);
```

{{ $\text{this.list} = \text{cons}(x, \text{this.list}_0)$ and $\textbf{this.last = last(this.list}_0\textbf{)}$ }}

{{ **Post**: $\text{obj} = \text{cons}(x, \text{obj}_0)$ and this.last = last(this.list) }}

```
  };
```

Rep Invariant would not hold if we switched the order

Mutable List ADT with a Fast `getLast`

```
class MutableFastListImpl implements MutableFastList {
  // RI: this.last = last(this.list)
  // AF: obj = this.list
  last: bigint | undefined;
  list: List<bigint>;

  // @modifies obj
  // @effects obj = cons(x, obj_0)
  cons = (x: bigint): void => {
    this.list = cons(x, this.list);
    this.last = last(this.list);
```

{{ this.list = cons(x, this.list$_0$) and this.last = last(this.list) }}

{{ **Post**: obj = cons(x, obj$_0$) and this.last = last(this.list) }}

```
  };
```

This version is obviously correct, but O(n).

Can we do it faster?

Mutable List ADT with a Fast `getLast`

```
class MutableFastListImpl implements MutableFastList {
  // RI: this.last = last(this.list)
  // AF: obj = this.list
  last: bigint | undefined;
  list: List<bigint>;

  // @modifies obj
  // @effects obj = cons(x, obj_0)
  cons = (x: bigint): void => {
    if (this.list === nil)
      this.last = x;
    this.list = cons(x, this.list);
    {{ ________________________________ }}
    {{ Post: obj = cons(x, obj₀) and this.last = last(this.list) }}
  };
```

O(1) version, but more complex reasoning (two branches)

Mutable List ADT with a Fast `getLast`

```
class MutableFastListImpl implements MutableFastList {

  cons = (x: bigint): void => {
    if (this.list === nil)
      this.last = x;
    this.list = cons(x, this.list);
    {{ this.list = cons(x, this.list_0) and this.list_0 = nil and this.last = x }}
    {{ Post: obj = cons(x, obj_0) and this.last = last(this.list) }}
  };
```

Case "then":

last(this.list)	= last(cons(x, this.list$_0$))	**since** this.list = cons(x, ...)
	= last(cons(x, nil))	**since** this.list$_0$ = nil
	= x	**def of** last
	= this.last	**since** x = this.last

func last(cons(x, nil)) := x
last(cons(x, cons(y, L)) := last(cons(y, L))

Mutable List ADT with a Fast `getLast`

```
class MutableFastListImpl implements MutableFastList {

  cons = (x: bigint): void => {
    if (this.list === nil)
      this.last = x;
    this.list = cons(x, this.list);
```

{{ this.list = cons(x, this.list_0) and $\text{this.list}_0 \neq$ nil and
this.last = this.last_0 and **this.last_0 = last(this.list_0)** }}

{{ **Post**: obj = cons(x, obj_0) and this.last = last(this.list) }}

from the RI
(will need this)

Case "else":

last(this.list)	= last(cons(x, this.list_0))	**since** this.list = cons(x, ...)
	= last(this.list_0)	**since** $\text{this.list}_0 \neq$ nil
	= this.last_0	**since** this.last_0 = last(this.list_0)
	= this.last	**since** this.last = this.last_0

func last(cons(x, nil)) := x
last(cons(x, cons(y, L))) := last(cons(y, L))

Moral of the Story for Mutable Heap State

- More mutation gave us better efficiency
  - saved memory
  - immutable version could be just as fast
- More mutation means more complex reasoning
  - more facts to keep track of
  - more ways to make mistakes
  - more work to make sure we did it right

Avoiding Representation Exposure

- Prevent aliasing of mutable state
  - otherwise, code outside your class can break it

- Options for avoiding representation exposure:

  1. Use immutable types

     lists are immutable, so you can freely accept and return them

  2. Copy In, Copy Out

     store copies of mutable values passed to you

     return copies of not aliases to mutable state

     don’t take their word that they haven’t kept an alias

- Professionals are untrusting about aliases

Need for Mutable Heap State

- Saw that mutable heap state is complex
  - better to avoid when possible
- Cannot be avoided in some cases
  1. server-side data storage (HW7-9)
  2. client-side UI (HW8-9)
- In both cases, we try to constrain its use
  - including coding conventions to keep ourselves sane

Stateful UI in React
(React Components)

UI in HW1-6

- UI so far was static
  - `index.tsx` calls `render` to show a fixed UI

    UI was different based on query params

    but never changed once rendered

- Made the UI change by reloading the page
  - change the query params, so it renders something different

UI in HW1-6

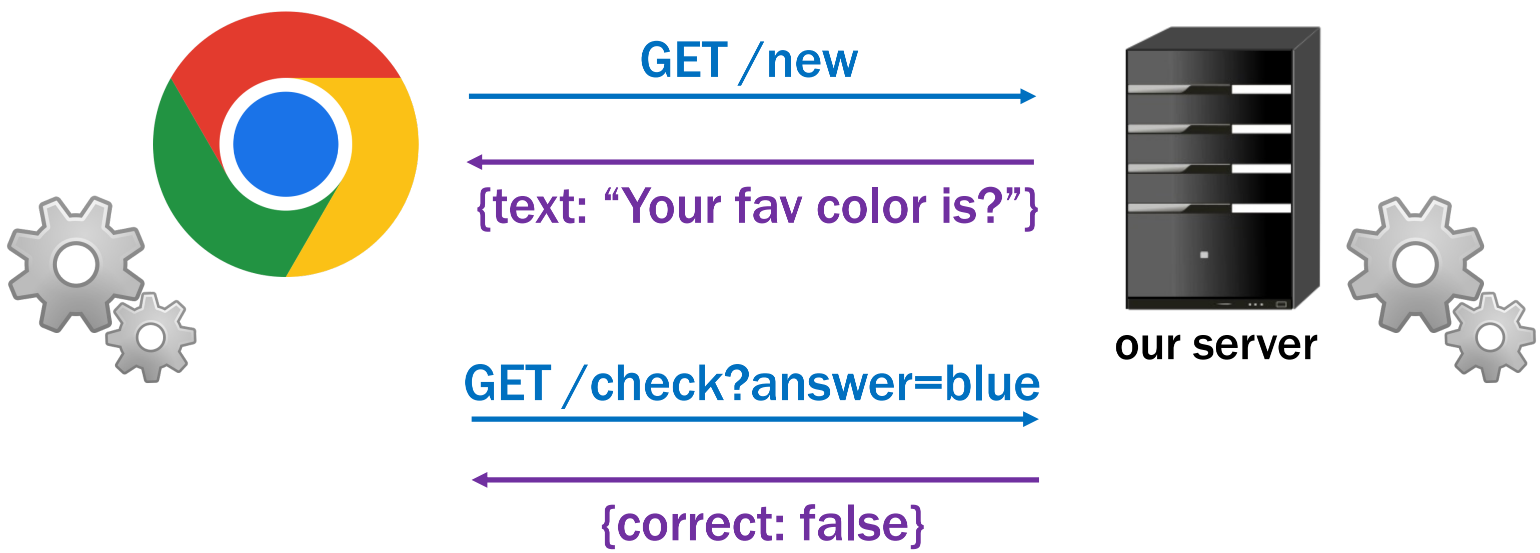
- Made the UI change by reloading the page
  - change the query params, so it renders something different

`http://localhost:8080/` → `http://localhost:8080/?word=wooow&...`


```
const word = params.get("word");
if (word === null) {
  root.render(<MakeForm/>);
} else {
  root.render(<ShowResults word={word} ../>);
}
```

Client-Side State

- Client needs to update the UI after getting response
  - don't want to reload the whole page to redraw
    reloading is slow and can lose user data (e.g., contents of text fields)
  - need a way to update the UI without a reload



React Functions

- React let us create custom tags
  - e.g., from HW3

```
root.render(<QuiltElem quilt={q}/>);
```

  - acts like the call

```
root.render(QuiltElem({quilt: q}));
```

  - where `QuiltElem` is function taking a record argument

```
const QuiltElem = (props: {quilt: Quilt}): JSX.Element => {..};
```

- Render spots `<QuiltElem>` and calls `QuiltElem`
  - replaces `<QuiltElem>` with HTML returned by `QuiltElem`

React Functions

- React let us create custom tags
  - e.g., from HW3

```
root.render(<QuiltElem quilt={q}/>);
```

  - acts like the call

```
root.render(QuiltElem({quilt: q}));
```

  - where `QuiltElem` is function taking a record argument

```
const QuiltElem = (props: {quilt: Quilt}): JSX.Element => {..};
```

- Gives modularity but UI cannot change
  - need *mutable* state to allow the UI to update after events

React Components

- React also let us create custom tags with classes
  - e.g., from HW3

```
root.render(<QuiltElem quilt={q}/>);
```

  - acts like the call

```
root.render(new QuiltElem({quilt: q}).render());
```

  - where `QuiltElem` is class that takes a record in constructor

```
class QuiltElem extends Component<{quilt: Quilt}, {}> {
  constructor(props: {quilt: Quilt}) { … /* store props */ }
  render = (): JSX.Element => { … /* return HTML */ };
};
```

Simplest React Component

- **Component that prints a Hello message:**

```
type HiProps = {name: string};

class HiElem extends Component<HiProps, {}> {
  constructor(props: HiProps) {
    super(props);
  }
  render = (): JSX.Element => {
    return <p>Hi, {this.props.name}</p>;
  };
}
```

- **Used as** `<HiElem name={"Fred"}/>`**:**

Simplest React Component

- Component that prints a Hello message:

```
type HiProps = {name: string};

class HiElem extends Component<HiProps, {}> {
  constructor(props: HiProps) {
    super(props);
  }
  render = (): JSX.Element => {
    return <p>Hi, {this.props.name}</p>;
  };
}
```

No sensible reason to make Components without state

- Component is a generic type
  - first type parameter is the type of "`props`"
  - second type parameter is for "`state`"...

Simplest Stateful React Component

```
type HiProps = {name: string};
type HiState = {greeting: string};

class HiElem extends Component<HiProps, HiState> {
  constructor(props: HiProps) {
    super(props);
    this.state = {greeting: "Hi"};
  }
```

- **Component is a generic type**
  - **first component is type of `this.props` (readonly)**
  - **second component is type of `this.state`**

- **Initialize `this.state` in the constructor**
  - **never directly modified after that**

React Components

```
type HiProps = {name: string};
type HiState = {greeting: string};

class HiElem extends Component<HiProps, HiState> {

  render = (): JSX.Element {
    return <p>{this.state.greeting},
                {this.props.name}!</p>;
  };
```

- `render` can use both `this.props` and `this.state`
  - difference 1: caller give us props, but we set our state
  - difference 2: we can *change* our state
  - React will automatically re-render when state changes

    re-render happens shortly after the state change

React Components

```
type HiProps = {name: string};
type HiState = {greeting: string};

class HiElem extends Component<HiProps, HiState> {
  …
  setGreeting = (newGreeting: string): void => {
    this.setState({greeting: newGreeting});
  };
}
```

- **Must call `setState` to change the state**
  - **directly modifying `this.state` is a (painful) bug**

    our linter will prevent this, thankfully

- **React will automatically re-render when state changes**
  - **this is the (only) reason to use a Component**

React Components

```
type HiProps = {name: string};
type HiState = {greeting: string};

class HiElem extends Component<HiProps, HiState> {
  …
  setGreeting = (newGreeting: string): void => {
    this.setState({greeting: newGreeting});
  };
}
```

- **Must call** `setState` **to change the state**
  - **directly modifying** `this.state` **is a (painful) bug**

    our linter will prevent this, thankfully

- **Only need to supply the fields that have changed**
  - **all the other fields will stay as they were before**

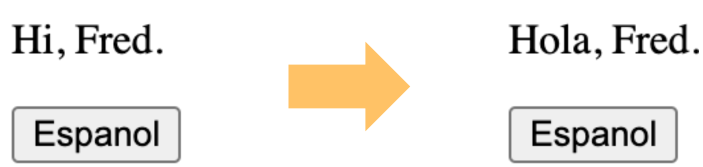
React Components

```
type HiProps = {name: string};
type HiState = {greeting: string};

class HiElem extends Component<HiProps, HiState> {
  constructor(props: HiProps) {
    super(props);
    this.state = {greeting: "Hi"};
  }

  render = (): JSX.Element {
    return <p>{this.state.greeting},
               {this.props.name}!</p>;
  };

  setGreeting = (newGreeting: string): void => {
    this.setState({greeting: newGreeting});
  };
}
```

React Components

```
type HiProps = {name: string};
type HiState = {curName: string};

class HiElem extends Component<HiProps, HiState> {
  …
  setGreeting = (newGreeting : string): void => {
    this.setState({greeting: newGreeting});
  };
}
```

- **How could** `setGreeting` **be called?**
  - **typically happens in a handler for an HTML event**



React Component with an Event Handler

- **Pass method to be called as argument (a "callback")**
  - **value of** `onClick` **attribute is our** `makeSpanish` **method**

```
render = (): JSX.Element {
   return (<div>
        <p>{this.state.greeting}, {this.props.name}!</p>
        <button onClick={this.doEspClick}>Espanol</button>
      </div>);
 };
```

- **Browser will invoke that method when button is clicked**

```
doEspClick = (evt: MouseEvent<HTMLButtonElement>) => {
   this.setState({greeting: "Hola"});
 };
```

  - **Call to** `setState` **causes a re-render (in a bit)**

React Component with an Event Handler

```
type HiProps = {name: string};
type HiState = {greeting: string};

class HiElem extends Component<HiProps, HiState> {
  constructor(props: HiProps) {
    super(props);
    this.state = {greeting: “Hi”};
  }

  render = (): JSX.Element {
    return (<div>
        <p>{this.state.greeting}, {this.props.name}!</p>
        <button onClick={this.doEspClick}>Espanol</button>
      </div>);
  };

  doEspClick = (evt: MouseEvent<HTMLButtonElement>) => {
    this.setState({greeting: “Hola”});
  };
```

React Component with an Event Handler

- Pass method to be called as argument (a “callback”)
  - value of `onClick` attribute is our `makeSpanish` method

```
render = (): JSX.Element {
   return (<div>
        <p>{this.state.greeting}, {this.props.name}!</p>
        <button onClick={this.doEspClick()}>Espanol</button>
      </div>);
 };
```

- Including parentheses here is a (painful) bug!
  - that would call the method inside render

    passing its return value as the value of the `onClick` attribute
  - we want to pass the method to the button, and have it called when the click occurs

Event Handler Conventions

- We will use this convention for event handlers

$$\texttt{do}\underbrace{\texttt{MyComp}}_{\text{component name}}\underbrace{\texttt{MyEvent}}_{\text{event name}}$$

  - e.g., `doAddClick`, `doNewNameChange`

- Reduces the need to explain these methods
  - method name is enough to understand what it is for
  - method name is the only thing you know they read

- Components should be just rendering & event handlers

React Components are Like ADTs

```
type HiProps = {name: string};
type HiState = {greeting: string};
```

- “Props” are part of the specification (arguments)
  - public interface, used by clients

```
root.render(<Hi name={“Fred”}/>);   // pass in name
```

- “State” is like the concrete representation
  - private choice of data structures, hidden from clients

```
constructor(props: HiProps) {
  super(props);
  this.state = {greeting: “Hi”};    // initial state
}
```

React Components are Like ADTs

- Can have RIs on state as well
  - write down any necessary facts not included in the types

```
// RI: 0 <= index < options.length
type OptionState = {
  options: string[],
  index: bigint
};
```

- Good idea to write code to double check this
  - a `checkRep` method is good defensive programming

    (see also `CheckInv1` in HW7 for complex loops)

React Components are Like ADTs

- HTML on the screen is a (hidden) part of the state
  - components work with React to manage this state

- `render` method is like an AF
  - function applied to the state to make something important
  - defines what it looks like, rather than what it means

- Components have an extra invariant like an RI

$$\text{HTML on screen} = \text{render}(\text{this.state})$$

React Components are Like ADTs

HTML on screen = render(this.state)

	Component	React
$t = 10$	$\text{this.state} = s_1$	$\text{doc} = \text{HTML}_1 = \text{render}(s_1)$
$t = 20$	$\text{this.setState}(s_2)$	
$t = 30$	$\text{this.state} = s_2$	$\text{doc HTML}_2 = \text{render}(s_2)$

React updates this.state **to** s_2 **and** doc **to** HTML_2 ***simultaneously***

React Components are Like ADTs

- **Components have an extra invariant like an RI**

  $$\text{HTML on screen} = \text{render}(\text{this.state})$$

  – **don't want to be in a state where that is not true**

    unless you like **painful** debugging!

  1. **Do not mutate `this.state` (call `setState`)**

     React will update `this.state` and HTML on screen at the same time

     Easy way to ensure this: disallow mutation in the client

     We'll use that rule this quarter.

React Components are Like ADTs

- **Components have an extra invariant like an RI**

  HTML on screen = render(this.state)

  - **don't want to be in a state where that is not true**

    unless you like **painful** debugging!

1. **Do not mutate `this.state` (call `setState`)**

   React will update `this.state` and HTML on screen at the same time

2. **Make sure no data on screen would disappear on re-render**

   More on this later…

React Components have Mutable Heap State

- Like ADTs, methods are sharing state
  - change in one method is read in other methods
- Error in one method (writing) fails in another (reading)
  - debugging will be harder!
- HW8-9 are the debugging assignments
  - necessary to understand all the parts of the code

React Components have Mutable Heap State

- Hard debugging makes correctness more important
- Move complex parts into separate functions
  - test and reason carefully through those functions
  - class is ideally just be rendering and event handlers

    move everything complex into helper functions

    e.g., calculation of new state can be a helper function
  - harder to reason about and test with mutable heap state, so keep it simple
- Write code to check your invariants
  - ensure the new state is valid before calling `setState`
  - practice defensive programming

Example: To-Do List (v1)

TodoApp – State

```
// Represents one item in the todo list.
type Item = {
  name: string;
  completed: boolean;
};

// Client gives us the initial (complete) list of items.
type TodoProps = {
  initialItems: Item[];  // items to show initially
};

// State of the app is the current list of items,
// which will be the initial list with some possibly removed.
type TodoState = {
  items: Item[];          // current list of items
};
```

TodoApp – Class

```
// Application that displays a to-do list.
export class TodoApp extends Component<{}, TodoState> {

  constructor(props: {}) {
    super(props);

    this.state = {items: props.initialItems.slice(0)};
  }

  …
```

TodoApp – Render

```
// Return a UI with all the items and elements that allow them to
// add a new item with a name of their choice.
render = (): JSX.Element => {
  return (
    <div>
      <h2>To-Do List</h2>
      {this.renderItems()}
    </div>);
}
```

TodoApp – Render Items (abbreviated)

```
renderItems = (): JSX.Element[] => {
  const items: JSX.Element[] = [];
  for (let i = 0; i < this.state.items.length; i++) {
    if (!this.state.items[i].completed) {
      items.push(
        <div className="form-check" key={i}>
          <input className="form-check-input" type="checkbox"
                 id={"check" + i} checked={false}
                 onChange={evt => this.doItemChange(evt, i)} />
          <label className="form-check-label" htmlFor={"check"+i}>
            {this.state.items[i].name}
          </label>
        </div>);
    } else { … /* read-only once completed */ }
  }
  return items;
};
```

TodoApp – Item Click

```
// Called when the user clicks on an item.
// Removes it from the list and redraws
doItemChange = (evt: ChangeEvent<HTMLInputELement>,
                index: number): JSX.Element => {
  const newItems = this.state.items.slice(0, index).concat(
      this.state.items.slice(index + 1));
  this.setState({items: newItems});
}
```

Example: To-Do List (v2)

TodoApp – State

```
// Represents one item in the todo list.
type Item = {
  name: string;
  completed: boolean;
};

// State of the app is the list of items and the text that the
// the user is typing into the new item field.
type TodoState = {
  items: Item[];     // existing items
  newName: string;   // mirrors text in the field to add a new name
                     //    (need this for two reasons…)
};
```

TodoApp – Class

```
// Application that displays a to-do list.
export class TodoApp extends Component<{}, TodoState> {

  constructor(props: {}) {
    super(props);

    this.state = {items: [], newName: ""};
  }

  …
```

TodoApp – Render

```
// Return a UI with all the items and elements that allow them to
// add a new item with a name of their choice.
render = (): JSX.Element => {
  return (
    <div>
      <h2>To-Do List</h2>
      {this.renderItems()}
      <p className="instructions">Check an item to mark it…</p>
      <p className="more-instructions">New item:
        <input type="text" className="new-item"
               value={this.state.newName}
               onChange={this.doNewNameChange} />
        <button type="button" className="btn btn-link"
                onClick={this.doAddClick}>Add</button>
      </p>
    </div>);
}
```

TodoApp – Render

```
// Return a UI with all the items and elements that allow them to
// add a new item with a name of their choice.
render = (): JSX.Element => {
  return (
    <div>
      <h2>To-Do List</h2>
      {this.renderItems()}
      <p className="instructions">Check an item to mark it…</p>
      <p className="more-instructions">New item:
        <input type="text" className="new-item"
               value={this.state.newName}
               onChange={this.doNewNameChange} />
        <button type="button" className="btn btn-link"
                onClick={this.doAddClick}>Add</button>
      </p>
    </div>);
}
```

TodoApp – Add Click

```
// Called when the user clicks on the button to add the new item.
doAddClick = (_: MouseEvent<HTMLButtonElement>): void => {
  // Ignore the request if the user hasn't entered a name.
  const name = this.state.newName.trim();
  if (name.length == 0)
    return;

  // Cannot mutate this.state.items! Must make a new array.
  const items = this.state.items.concat(
      [ {name: name, completed: false} ]);
  this.setState({items: items, newName: ""});  // clear input box
};
```

TodoApp – Render

```
// Return a UI with all the items and elements that allow them to
// add a new item with a name of their choice.
render = (): JSX.Element => {
  return (
    <div>
      <h2>To-Do List</h2>
      {this.renderItems()}
      <p className="instructions">Check an item to mark it…</p>
      <p className="more-instructions">New item:
        <input type="text" className="new-item"
               value={this.state.newName}
               onChange={this.doNewNameChange} />
        <button type="button" className="btn btn-link"
                onClick={this.doAddClick}>Add</button>
      </p>
    </div>);
}
```

TodoApp – New Name Change

```
// Called each time the text in the new item name field is changed.
doNewNameChange = (evt: ChangeEvent<HTMLInputElement>): void => {
  this.setState({newName: evt.target.value});
}
```

- Most event handlers are passed an **event** object
  - field "`evt.target`" stores the object that fired the event
  - hence, "`evt.target.value`" is the text in that input box

- Make sure no data on screen would **disappear** on re-render
  - must record the text the user typed into the field

    goes into the value={..} attribute of the input box
  - otherwise, render would produce an input box with no text

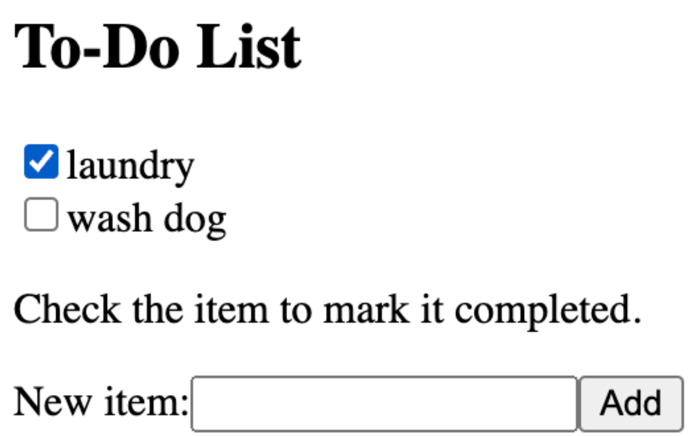
Other Events

- Components should be just rendering & event handlers
  - our linter will enforce this
- Timers have events that fire after a given time
  - call to `setTimeout` invokes callback after a delay

Example: Auctions

More Complex UI

- To-Do List UI is basic
  - all of it easily fits in a single component (`TodoApp.tsx`)



- More complex UI can be too much code for one file
  - necessary to split it into multiple components

Recall: Other Properties of High-Quality Code

- Professionals are expected to write high-quality code
- Correctness is the most important part of quality
  - users hate products that do not work properly
- Also includes the following:
  - easy to understand
  - easy to change
  - modular

via abstraction

Component Modularity

- Poor design to put all the app in one Component
  - it works, but is lacks properties of high-quality code
  - better to break it into smaller pieces (modular)

- Two ways to the UI into separate components:

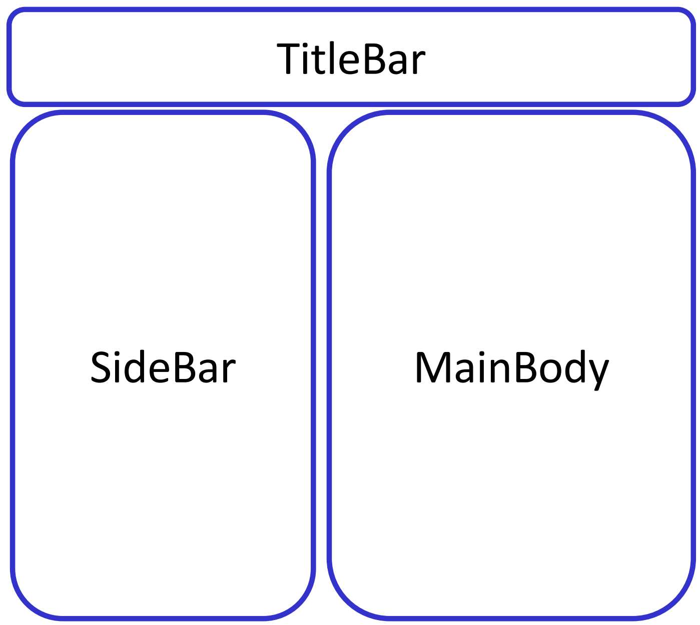
  1. Separate parts that are next to each other on screen

  2. Separate parts on the screen at different times

Component Modularity

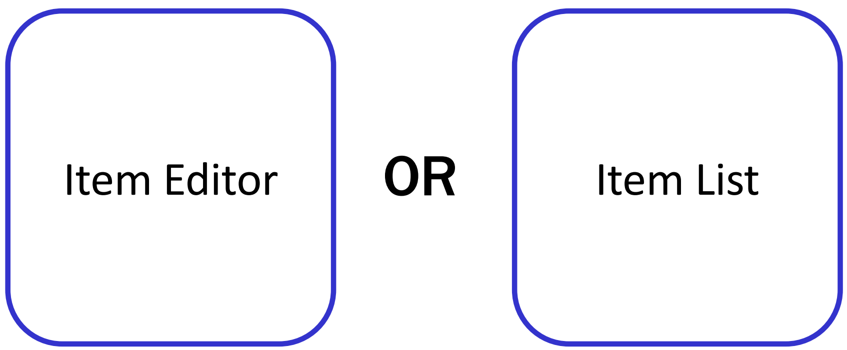
- **Separate parts that are next to each other**

```
class App extends Component<..> {
  render = (): JSX.Element {
    return (<div>
        <TitleBar title={“My App”}/>
        <SideBar/>
        <MainBody/>
      </div>);
  };
}
```



Component Modularity

- Separate parts on the screen at different times
- App is always on the screen
  - App chooses which child component to display



  - sometimes it has an Editor child and sometimes not

Component Modularity

- **Separate parts on the screen at different times**

```
type AppState = {editItem: string | undefined};

class App extends Component<{}, AppState> {
  …
  render = (): JSX.Element {
    if (this.state.editItem !== undefined) {
      return <ItemEditor item={this.state.editItem}/>;
    } else {
      return <ItemList/>;
    }
  };
  …
}
```

Example: Auctions

Example: Auction UI

- Auction site has three different "pages"

Current Auctions

- Oak Cabinet ends in 10 min
- Red Couch ends in 15 min
- Blue Bicycle

New

New Auction

Name Bob

Item Table Lamp

...

Oak Cabinet

A beautiful solid oak cabinet. Perfect for any bedroom. Dimensions are 42" x 60".

Current Bid: $250

Name Fred

Bid 251

Submit

Example: Auction UI

- Auction site has three different "pages"

- Need four different components:
  - Auction List: shows all the auctions (and Add button)
  - Auction Details: shows details on the auction (w Bid button)
  - New Auction: lets the user describe a new auction
  - **App**: decides which of these pages to show

Auction Client: `App.tsx`

- state needs to indicate which page to be showing

```
// RI: 0 <= index < auctions.length
type Page = {kind: "list"} | {kind: "new"} |
            {kind: "details", index: number};

type AppState = {page: Page, auctions: Auction[]};

class App extends Component<{}, AppState> { … }
```

- What is `Page` an example of?

  it is an **inductive data type** (of the "enum" variety)

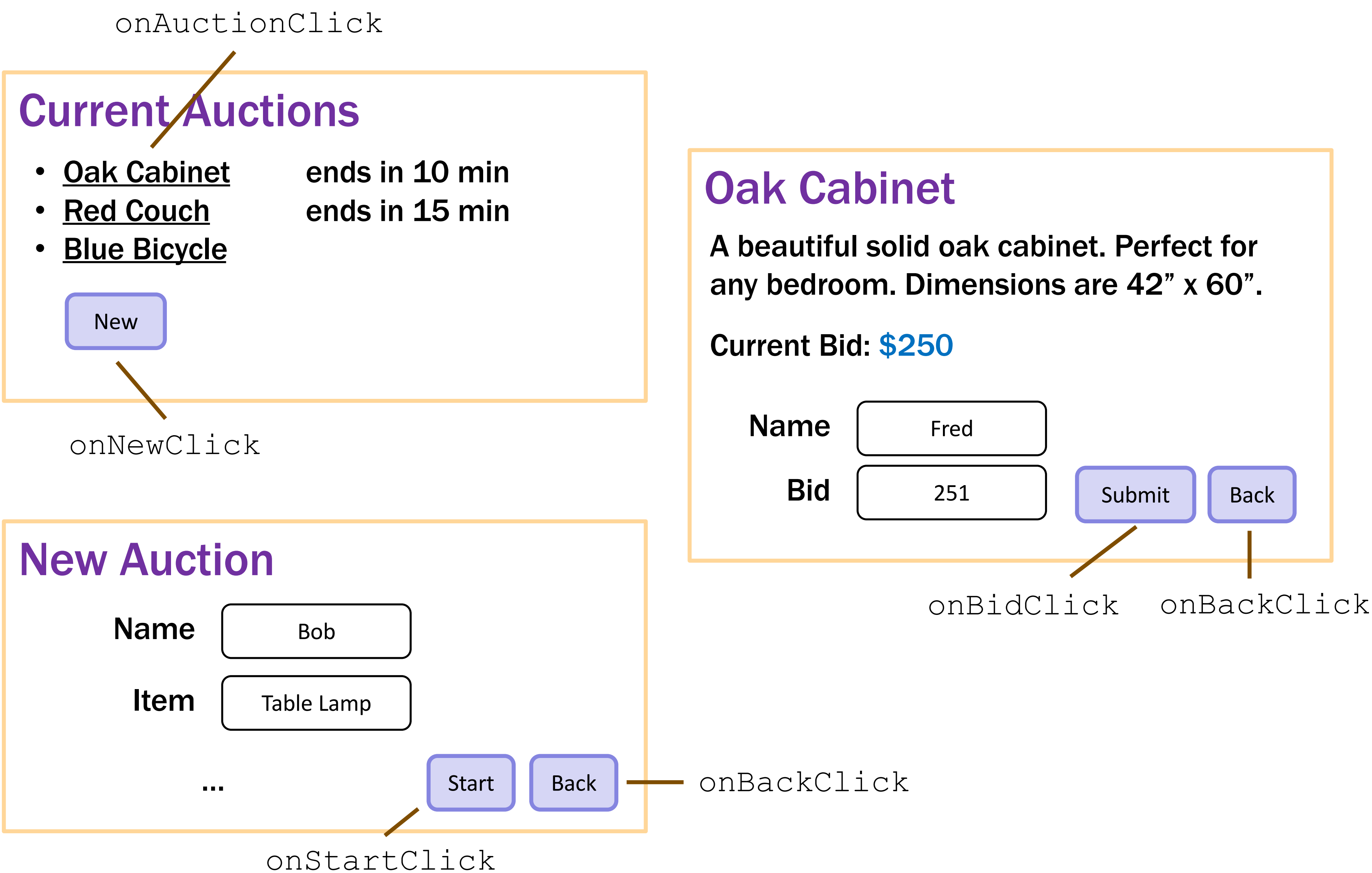
$$\textbf{type}\ \text{Page} := \text{list} \mid \text{new} \mid \text{details}(n : \mathbb{N})$$

Auction Client: `App.tsx`

– **render shows the appropriate UI**

```
render = (): JSX.Element => {
  if (this.state.page.kind === "list") {
    return <AuctionList auctions={this.state.auctions}
                  onNewClick={this.doNewClick}
                  onAuctionClick={this.doAuctionClick}/>;

  } else if (this.state.page.kind === "new") {
    return <NewAuction onStartClick={this.doStartClick}
                      onBackClick={this.doBackClick}/>;

  } else {  // kind: "details"
    const auction = this.state.auctions[this.state.page.index];
    return <AuctionDetails auction={auction}
                  onBidClick={this.doBidClick}
                  onBackClick={this.doBackClick}/>;
  }
};
```

Example: Auction UI



Auction Client: `App.tsx`

– event handlers change what is shown

```
doNewClick = (): void => {
  this.setState({page: "new"});  // show new auction page
};

doBackClick = (): void => {
  this.setState({page: "list"}); // show auction list page
};

doAuctionClick = (index: number): void => {
  // show details list page for the given auction
  this.setState({page: {kind: "details", index: index}});
};
```

Auction Client: `App.tsx`

- **the `App` component stores the auction list**

  easy to pass it down to subcomponents in their props

- **subcomponents cannot mutate the auction list!**

  they must invoke **callbacks** to have the `App` update the auction list

```
doStartClick = (name: string, seller: string, …): void => {
  const auction = {name, seller, …};
  const auctions = this.state.auctions.concat([auction]);
  this.setState({page: "list", auctions: auctions});
};

doBidClick = (index: number, bidder: string, amount: number) => {
  const newVal = …;  // update the auction to have a new high bidder
  const auctions = this.state.auctions.slice(0, index)
        .concat([newVal])
        .concat(this.state.auctions.slice(index+1));
  this.setState({auctions: auctions,
                 page: {kind: "details", index: index}});
};
```

Next Up: “Full Stack” (Client & Server)

- Stateful client: error in one method fails in another
  - bug in writing new state shows up when reading it
- Client-server: error in one part can fail in the other
  - bug in client shows up as server crash
  - bug in server shows up as client crash
- HW8-9 are the debugging assignments
  - necessary to understand all the parts of the code