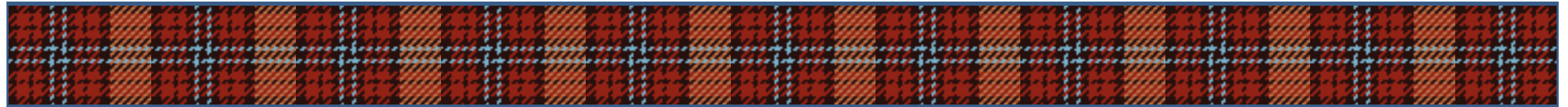
PLAID: Programming with Typestate and Permissions



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Motivation

- **Principles**
  - Object-Oriented modeling provides a powerful metaphor for designing and understanding programs
  - Types aid understanding and correctness by providing checkable documentation

- **Goals for Plaid:**
  - Build an object oriented language with explicit support for objects that follow protocols
  - Develop a static type system to help programmers reason about protocols

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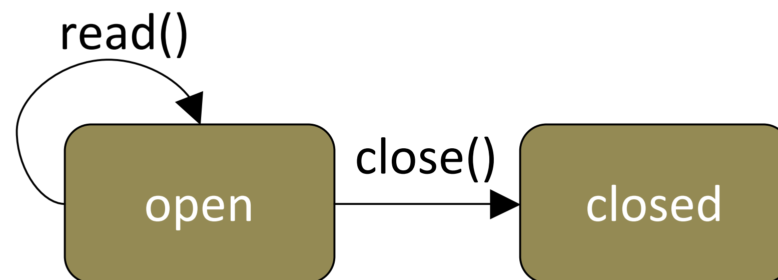
Object Protocols

- A protocol dictates an order on method calls to the object
- Example: FileReader
  - Sometimes you can read from the file, sometimes you cannot
  - Depends on whether the File is **Open** or **Closed**
- Modeled by **Abstract States**
  - read() method only available in the Open state
  - Calling close() **changes** the abstract state of the object to Closed
- Recognized in design tools
  - State Machines
  - UML State Charts



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Object Protocols in Java

```
package java.io;
class FileReader {
    int read() { … }
    …
    /** Closes the stream and releases any system resources associated with it.
    Once the stream has been closed, further read(), ready(), mark(), reset(), or
    skip() invocations will throw an IOException. Closing a previously closed stream
    has no effect. **/
    void close() { … }
}
```

- Why is this a poor model?
  - Interface does not change
  - The abstract state is not explicit
  - The protocol is encoded as textual comments

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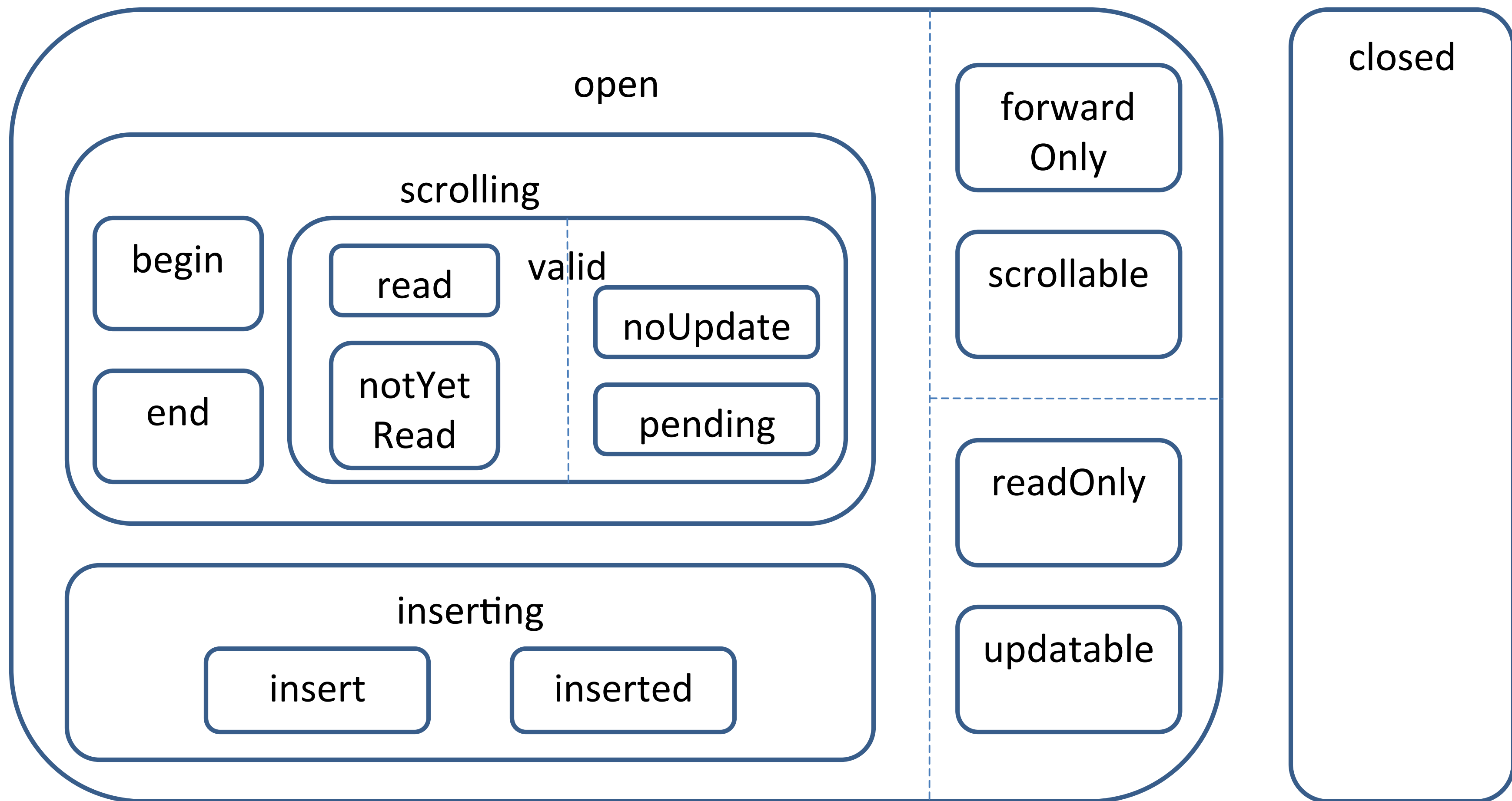
ResultSet State Space

Java Database Connectivity (JDBC) Library State Space



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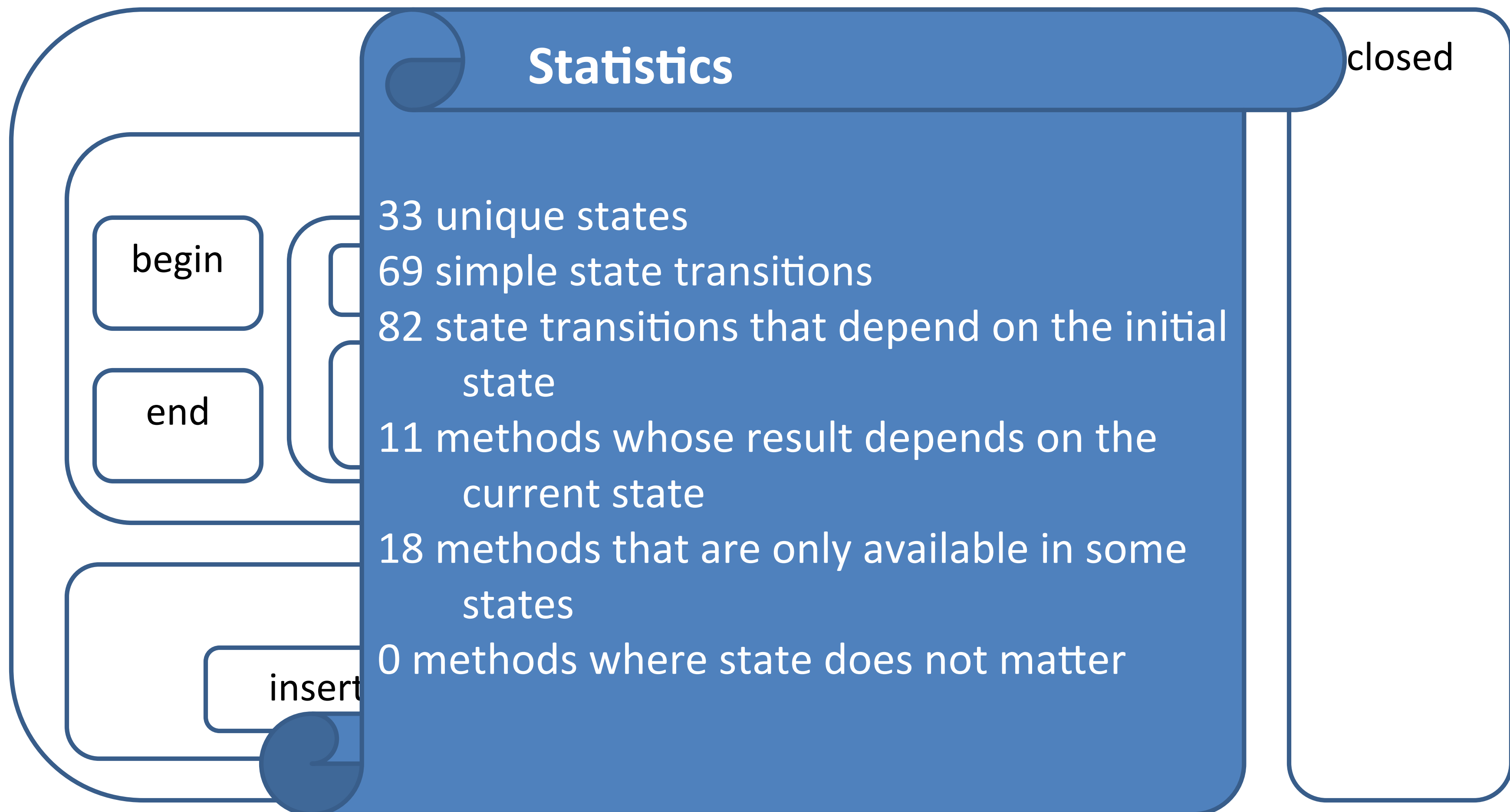
ResultSet State Space

Java Database Connectivity (JDBC) Library State Space



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Why Do We Need Plaid?

1. Modeling important for complex protocols

   ResultSet, Frameworks (ASP.NET, Swing, etc.), Java iterators

   - Explicit questions about states
   - Errors that refer to the design
   - Types for documentation and verification of definition and use

2. Object Protocols are prevalent:

   - Study of protocols in Java Standard Library and open source projects
   - At least 7% of Java classes **define** a protocol
     (compare to 2.5% of classes which are generic)
   - At least 13% of Java classes **use** a protocol

Typestate

- Idea: break object definition up into **Typestates**
- Like Types:
  - Provide and **Interface**
  - Define **Behavior** via methods
  - Specify **Representation** via fields
- But not fixed:
  - An object's typestate can change over its lifetime

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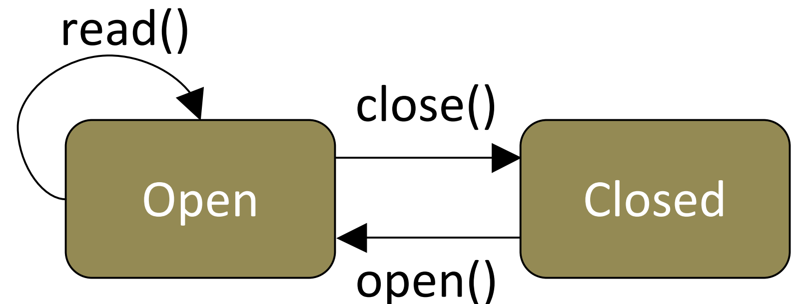
Dynamic Typestates in Plaid

- **state** = class
- **case of** = extends




```
state File {
    val filename;
}
```

```
state Open case of File {
    val filePtr;
    method read() {…}
    method close() { this <- Closed; }
}
```

```
state Closed case of File {
    method open() { this <- Open; }
}
```

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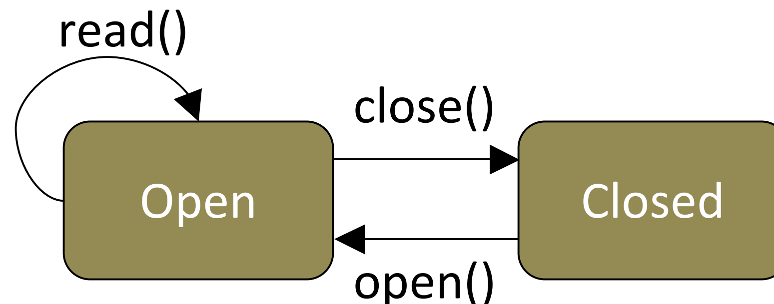
Asking State Questions

- Query dynamic state with **match**
- Syntax notes
  - First class functions
  - Expression based syntax returns value of last expression in a block

```
val readChar = fn (file) => {
    match(file) {
        case Open { /* No Op*/ }
        case Closed { file.open(); }
    };
    file.read();
};
```



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Types for Typestate

- States define nominal types like Java classes
- Careful with transitions
  - Aliasing
- Solution: **Permissions**

```
val closeTwo =
  fn (openFile1, openFile2) => {
    openFile1.close();
    openFile2.close();
  };

val badFunction =
  fn (openFile) => {
    closeTwo(openFile, openFile);
  };
```

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Permissions

- Two purposes:
  1. Summarize level of aliasing for referenced object
  2. Determine what actions can be taken via the reference
- **unique** permission:
  1. No other usable (non-**none**) aliases exist
  2. No restrictions on use
- **immutable** permission:
  1. Any other usable (non-**none**) alias must be **immutable**
  2. Cannot change the state of the object
- **none** permission:
  - Arbitrary aliases
  - Unusable

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Annotating States

- All types include a permission and a nominal typestate
- **Change Types** for the receivers of methods
  - Starting permission and type
  - Ending permission and type

```
state Open case of File {
  val unique FileRef filePtr;
  method
    read()[immutable Open >>
           immutable Open] {…}
  method
    close()[unique Open >> unique Closed]
    { this <- Closed; }
}
```

```
state Closed case of File {
  method
    open()[unique Closed >> unique Open]
  { this <- Open; }
}
```

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Typing and Rejecting Programs

- Change Types for parameters too
- Permissions and Types tracked through body of function
  - closeTwo fulfills its contract
  - In badFunction, we need a **unique** when we only have a **none**

```
val closeTwo =
  fn (unique Open >> unique Closed f1,
      unique Open >> unique Closed f2)
  => {
    //f1:unique Open, f2: unique Open
    f1.close();
    //f1:unique Closed, f2: unique Open
    f2.close();
    //f1:unique Closed, f2: unique Closed
  };
val badFunction =
  fn (unique Open >> unique Closed f)
  => {
    //f:unique Open
    closeTwo(f,  //f:none Open
             f); //Error
  };
```

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Using immutable

- Sharing **immutable** objects
  - Same object can be passed into readTwo
- Regaining **unique**
  - Possible in some cases

```
val readTwo =
  fn (immutable Open>>immutable Open f1,
      immutable Open>>immutable Open f2)
  => { f1.read() + f2.read(); };

val badFunction =
   fn (unique Open >> unique Open f)
   => {
     //f:unique Open
     readTwo(f,  //f:immutable Open
             f); //f:immutable Open
     //f:unique Open
   };
```

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More coming to Plaid

- Other Permissions:
  - shared, full, pure, …
- Composition of states and protocols
- Flexibility in the typesystem
  - Permission casts
  - Gradual typing (types only where important)
- Static analyses using permissions
  - infer concurrency

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Challenges

- Keeping the type system manageable
  - Flexibility
  - Defaults
  - Aggressive tracking of permissions
  - Casting and other escape hatches
  - Gradual typing

- We need YOU to
  - Try the language
  - Tell us what works and what doesn't
  - contribute

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The Plaid Language

- Plaid models object protocols and provides
  - Language support for protocols and abstract states
  - A type system to help document and check protocols and their uses
- Try it
  - In your browser: http://www.plaid-lang.org/
  - Download: http://code.google.com/p/plaid-lang/
- Help Out
  - Contact us if you are interested in helping to move Plaid forward

http://www.plaid-lang.org/