CS 520

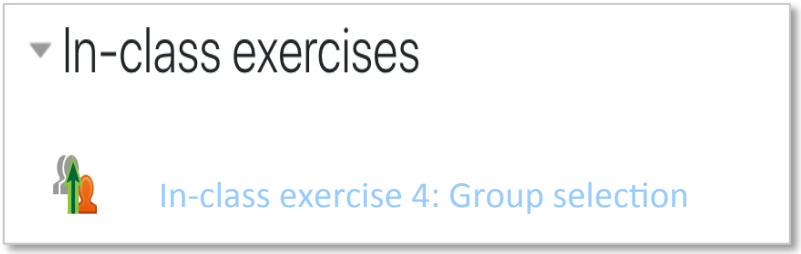
Theory and Practice of Software Engineering
Fall 2021

Model inference of processes

November 16, 2021

Thursday (November 18)

- Fourth (and last) in-class exercise
- On model inference of processes (today is a prelude with useful info)
- Form 3-, 4-, or 5- person teams
    - Use Moodle to self-select a team; open from today until Thursday at 11:59 PM (almost midnight)



Problem

- Missing or inaccurate system documentation makes it challenging to understand the intended system behaviors
- Complex logs of unintended system behaviors makes it difficult to debug them

Goal

- Take as input a set of observed **traces** (usually represented as sequences of **event**s) of a given system

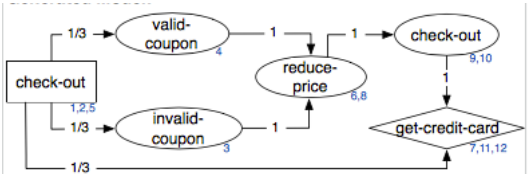
- Automatically produce an **inferred model** (often represented as an FSA) that must accept all of the observed traces
  - May also accept some unobserved traces

Model inference tool: Architecture [Synoptic]

Sequences of events
(often method calls)
[Log + Regular expressions]

Model inference algorithm [Bisim algorithm]

Inferred model
[Conceptually an FSA]



https://people.cs.umass.edu/~brun/pubs/pubs/Beschastnikh11fse.pdf

Shopping cart: API (written in PHP)

- invalid-coupon
- valid-coupon
- reduce-price
- check-out
- get-credit-card

BisimH algorithm

1. Extract a **trace graph** from a given **log** using the **regular expressions**
2. Mine **invariants** from that **trace graph**
3. Create **initial inferred model** by partitioning the **trace graph**
4. While (**current inferred model** violates **invariants**)
    1. Generate **counterexample path** through the current inferred model illustrating a violation of a given invariant
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1. Extract: Log and regular expressions

- Log, e.g.,

Line: 74.15.155.103 [06/Jan/2011:07:24:13] “GET HTTP/1.1/check-out.php”

- Regular expression(s), e.g.,

Line parsing: (?<ip>).+/(?<TYPE>.+).php

- Special events for INITIAL and TERMINAL. Each **event** specified as a triple <trace ID, timestamp, event type>,

  e.g., <74.15.155.103, 06/Jan/2011:07:24:13, check-out>

1. Extract: Trace graph

- Each **event** specified as a triple

  <trace ID, timestamp, event type>
  - Also special events for INITIAL and TERMINAL

- Each **trace** is a linear graph where:
  - Each event corresponds to a vertex
  - The total ordering among the events (specified by their timestamps) corresponds to the edges among the nodes

- A **trace graph** is the union of the set of traces

Shopping cart: Inputs

Log:

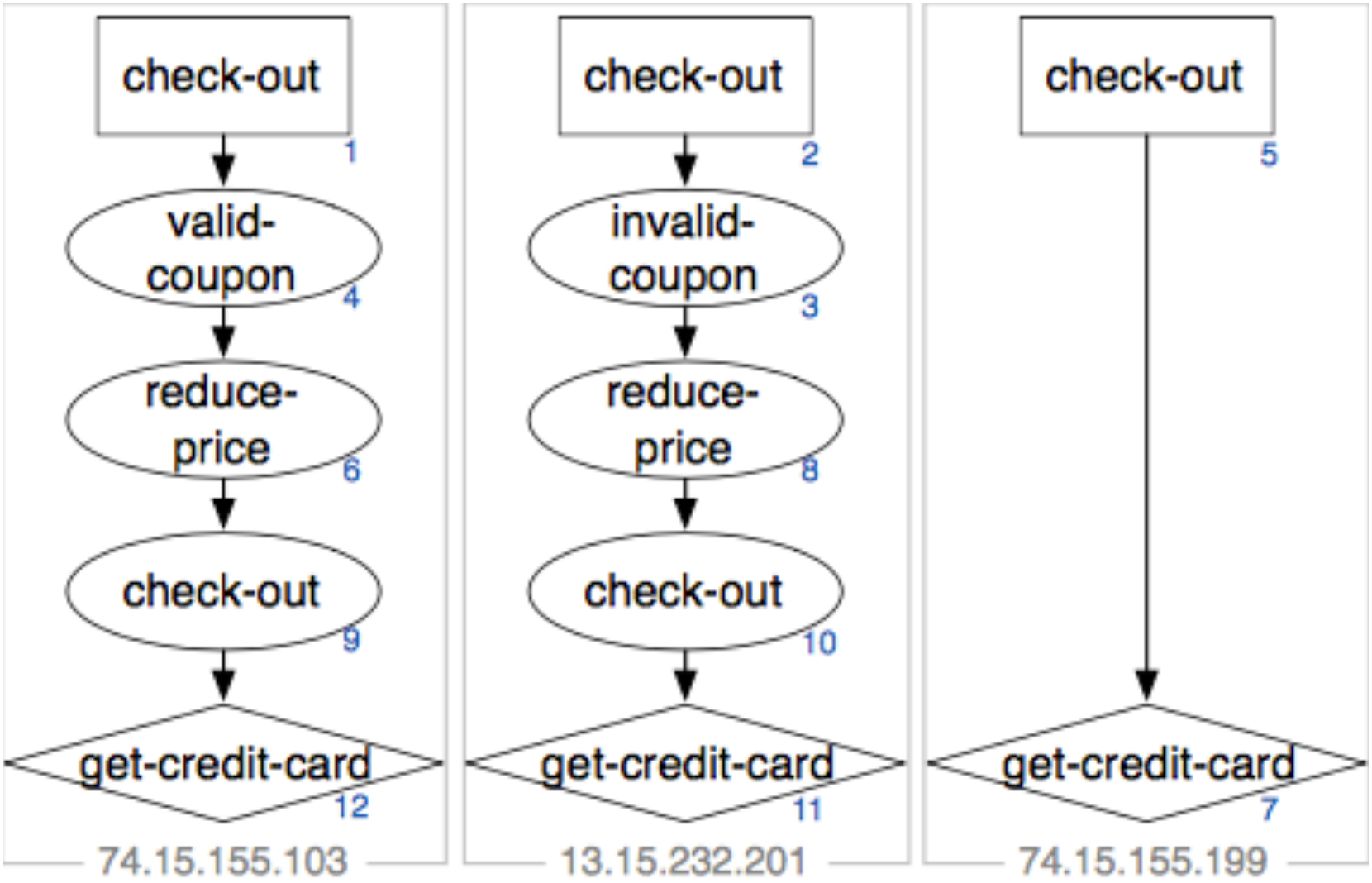
```
1  74.15.155.103 [06/Jan/2011:07:24:13] "GET HTTP/1.1 /check-out.php"
2  13.15.232.201 [06/Jan/2011:07:24:19] "GET HTTP/1.1 /check-out.php"
3  13.15.232.201 [06/Jan/2011:07:25:33] "GET HTTP/1.1 /invalid-coupon.php"
4  74.15.155.103 [06/Jan/2011:07:27:05] "GET HTTP/1.1 /valid-coupon.php"
5  74.15.155.199 [06/Jan/2011:07:28:43] "GET HTTP/1.1 /check-out.php"
6  74.15.155.103 [06/Jan/2011:07:28:14] "GET HTTP/1.1 /reduce-price.php"
7  74.15.155.199 [06/Jan/2011:07:29:02] "GET HTTP/1.1 /get-credit-card.php"
8  13.15.232.201 [06/Jan/2011:07:30:22] "GET HTTP/1.1 /reduce-price.php"
9  74.15.155.103 [06/Jan/2011:07:30:55] "GET HTTP/1.1 /check-out.php"
10 13.15.232.201 [06/Jan/2011:07:31:17] "GET HTTP/1.1 /check-out.php"
11 13.15.232.201 [06/Jan/2011:07:31:20] "GET HTTP/1.1 /get-credit-card.php"
12 74.15.155.103 [06/Jan/2011:07:31:44] "GET HTTP/1.1 /get-credit-card.php"
```

Regular Expressions:

Line parsing: “(?<ip>).+/(?<TYPE>.+).php”

Trace mapping: “\k<ip>”

Shopping cart: Trace graph



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2. Mine invariants

- Capture temporal relationships between **event types** in a given trace graph
  - a Always Followed by b (a $\rightarrow$ b)

    e.g., INITIAL $\rightarrow$ check-out
  - a Never Followed by b (a $\not\rightarrow$ b)

    e.g., valid-coupon $\not\rightarrow$ invalid-coupon
  - a Always Precedes b (a $\leftarrow$ b)

    e.g., check-out $\leftarrow$ get-credit-card

- Must be satisfied by all of the potential traces through that graph

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- Capture temporal relationships between **event types** in a given trace graph
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  - a Always Precedes b (a $\leftarrow$ b)
    e.g., check-out $\leftarrow$ get-credit-card

Use the Dwyer et al. property patterns

- Must be satisfied by all of the potential traces through that graph

Shopping cart: Invariants

[Show invariants as text]

AlwaysPrecedes (←)
check-out ← get-credit-card
check-out ← invalid-coupon
check-out ← reduce-price
check-out ← valid-coupon

AlwaysFollowedBy (→)
INITIAL → check-out
INITIAL → get-credit-card
check-out → get-credit-card
invalid-coupon → check-out
invalid-coupon → get-credit-card
invalid-coupon → reduce-price
reduce-price → check-out
reduce-price → get-credit-card
valid-coupon → check-out
valid-coupon → get-credit-card
valid-coupon → reduce-price

NeverFollowedBy (→)
get-credit-card → check-out
get-credit-card → get-credit-card
get-credit-card → invalid-coupon
get-credit-card → reduce-price
get-credit-card → valid-coupon
invalid-coupon → invalid-coupon
invalid-coupon → valid-coupon
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reduce-price → valid-coupon
valid-coupon → invalid-coupon
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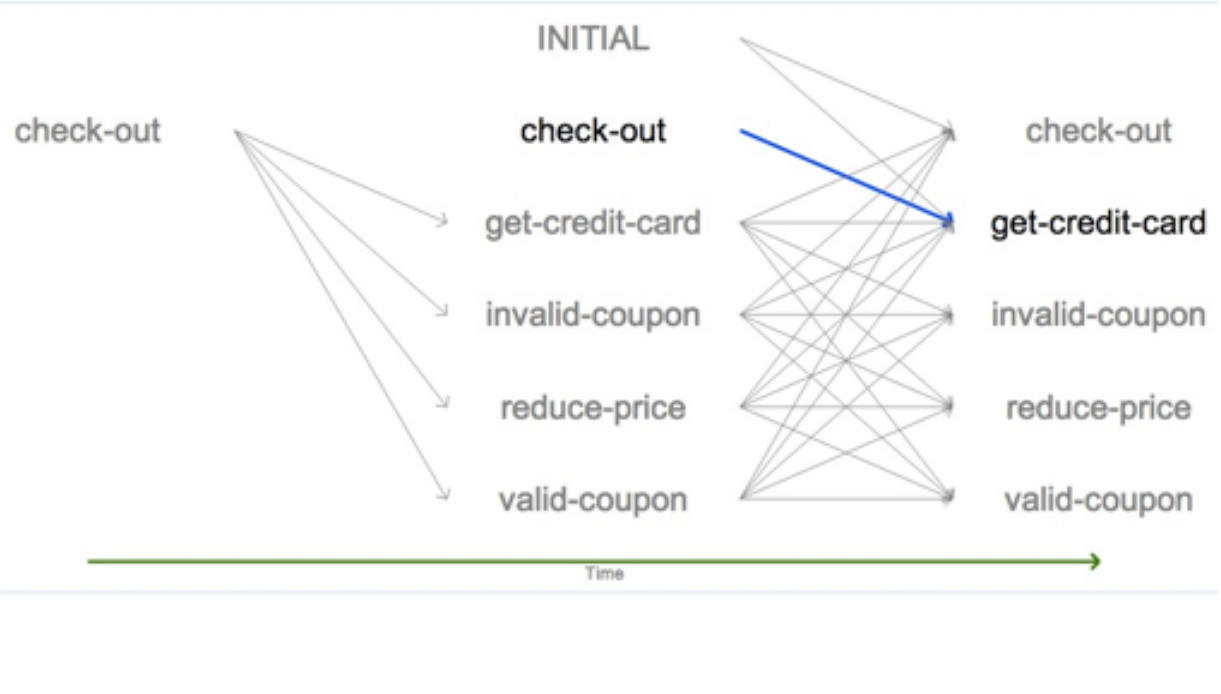

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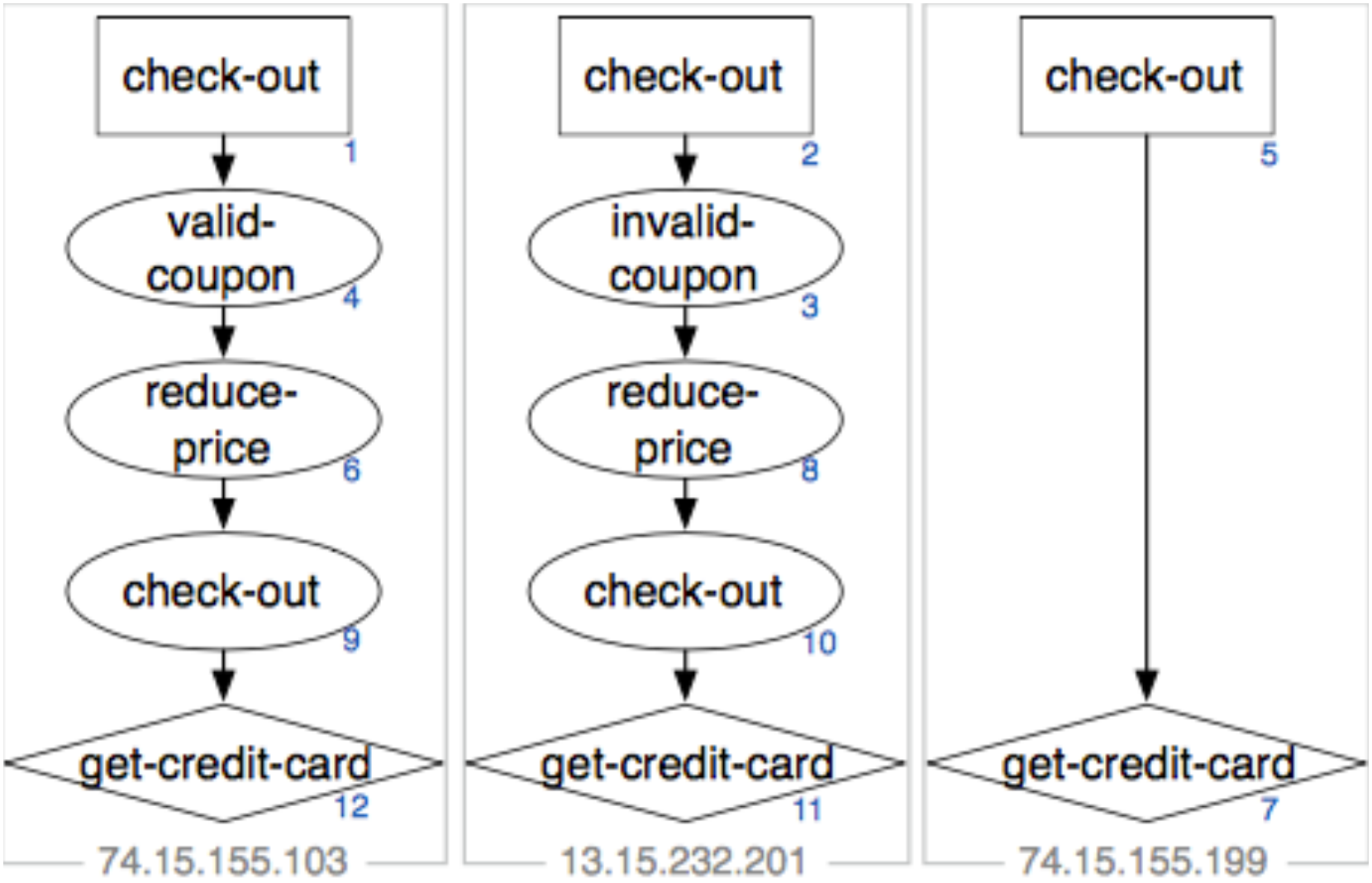
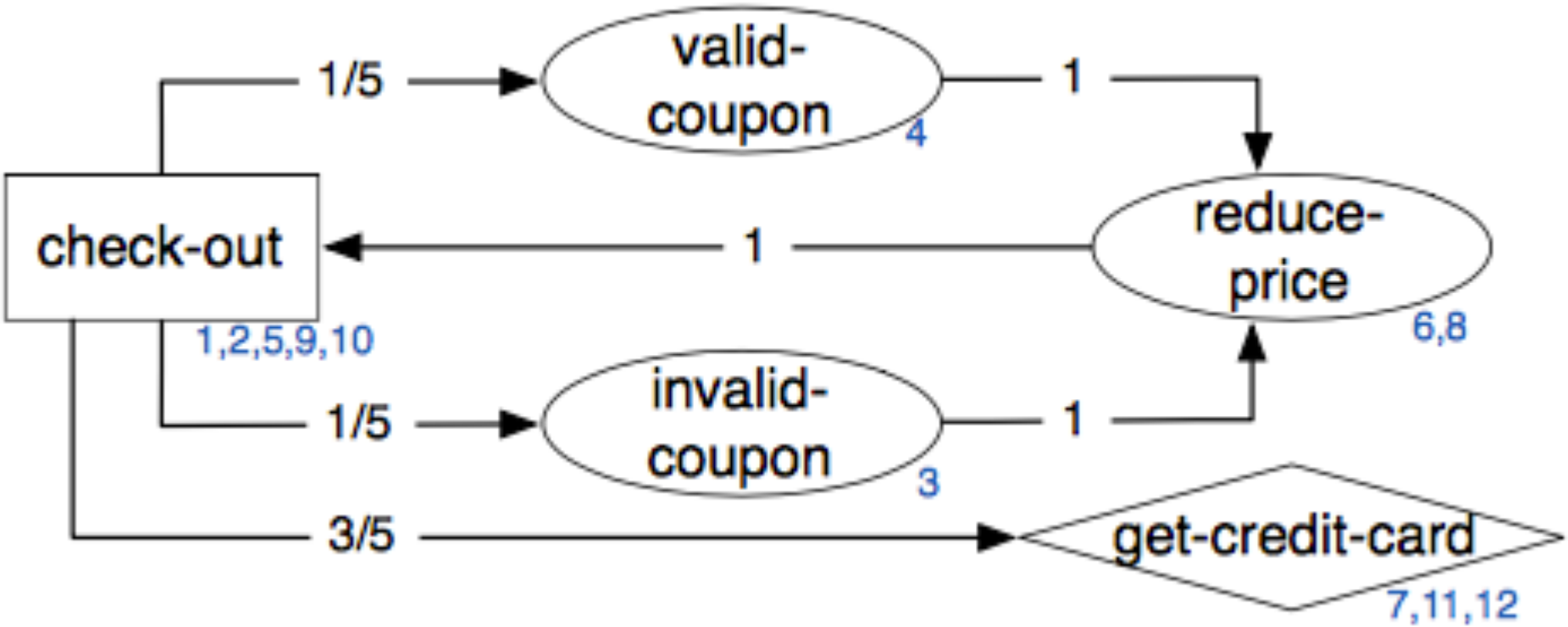
Shopping cart: Trace graph



Shopping cart: Initial model



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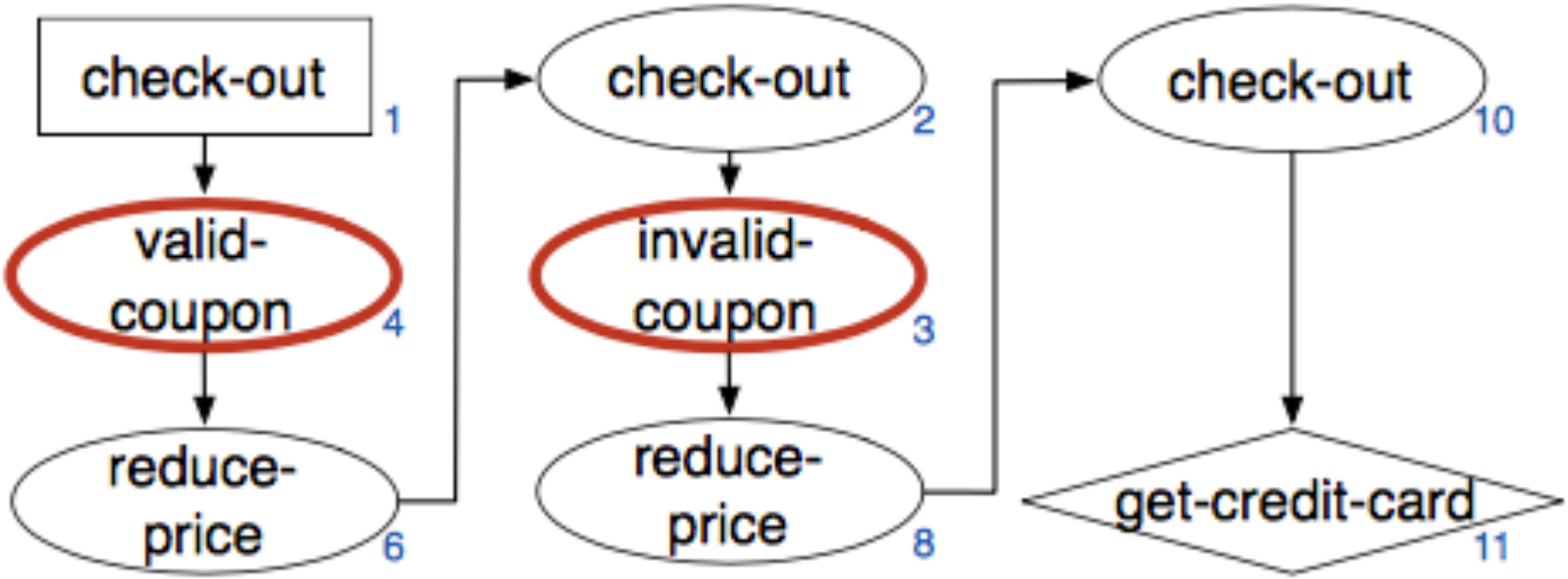
Use counterexample guided abstraction refinement (CEGAR)

4. CEGAR: Generate counterexample path

- Employ a model checker to determine if all potential paths through the **current inferred model** satisfy the **invariants**
  - If so, report satisfied
  - If not, report violated and a **counterexample path** illustrating a violation of one of the invariants

Shopping cart: Counterexample path

Violates invariant: valid-coupon $\not\rightarrow$ invalid-coupon

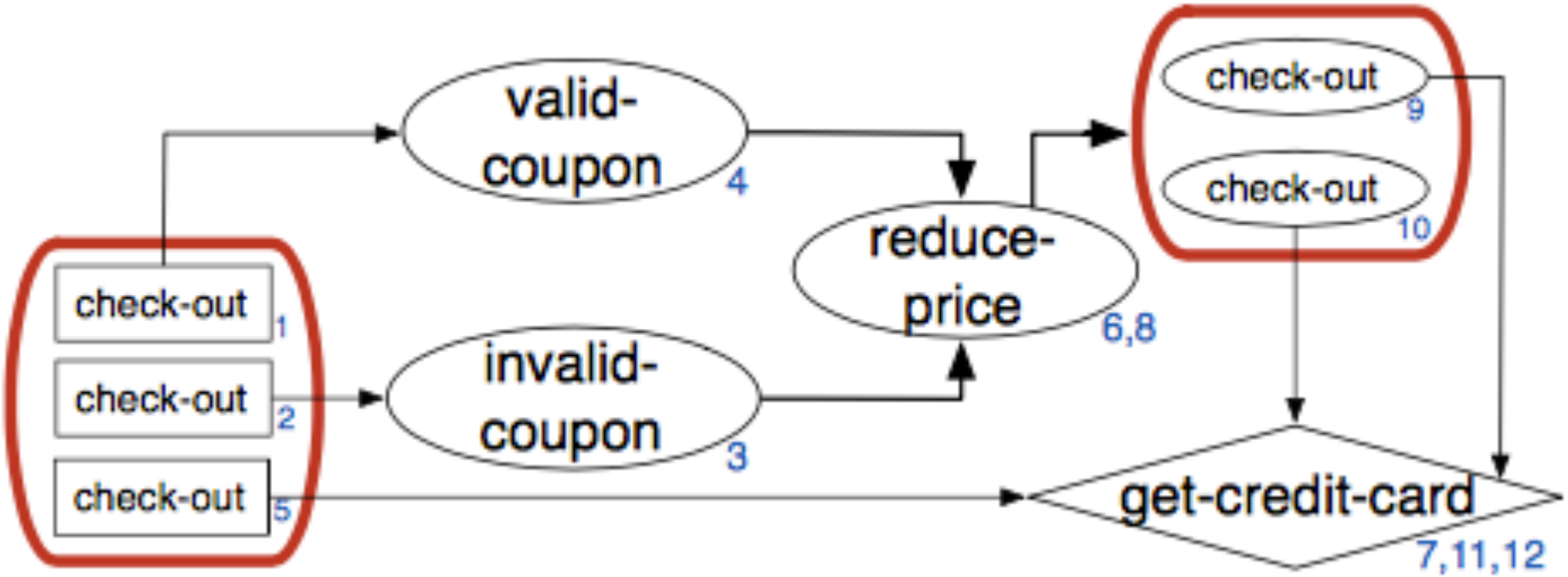


4. CEGAR: Refine

1. Refine the current inferred model based on the violated invariant
   - Heuristically select a vertex relevant to that invariant

2. Create the refined inferred model that satisfies that invariant
   - Split the selected vertex into multiple vertices

Shopping cart: Refined model

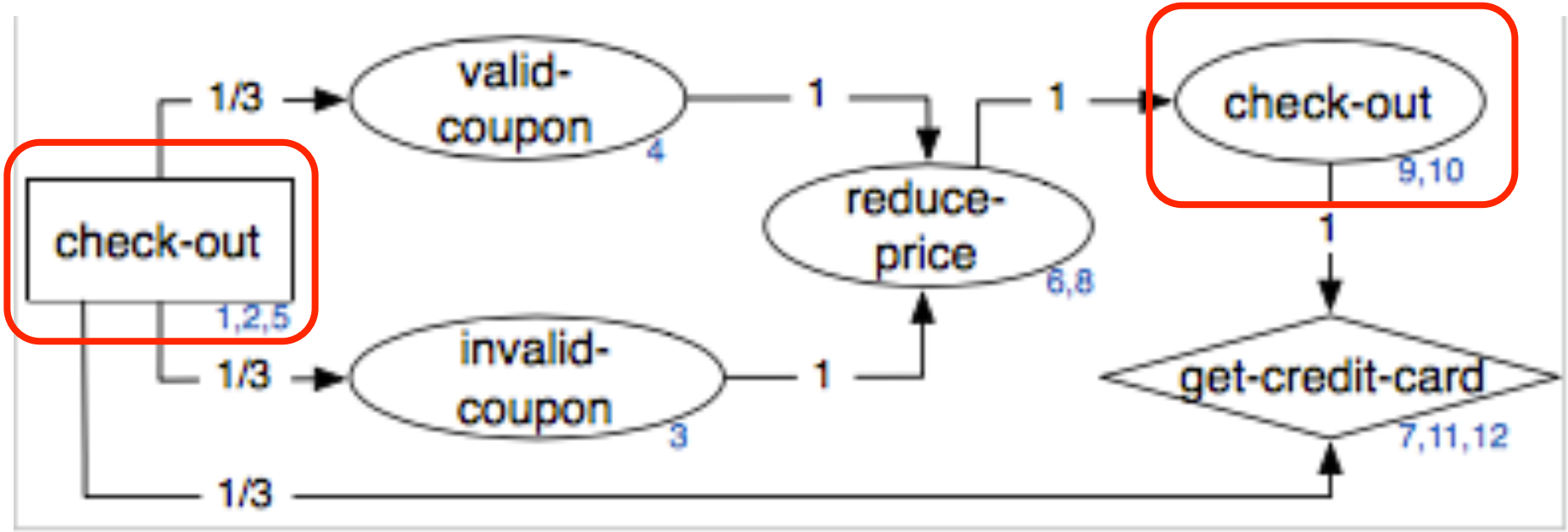


5. Coarsen

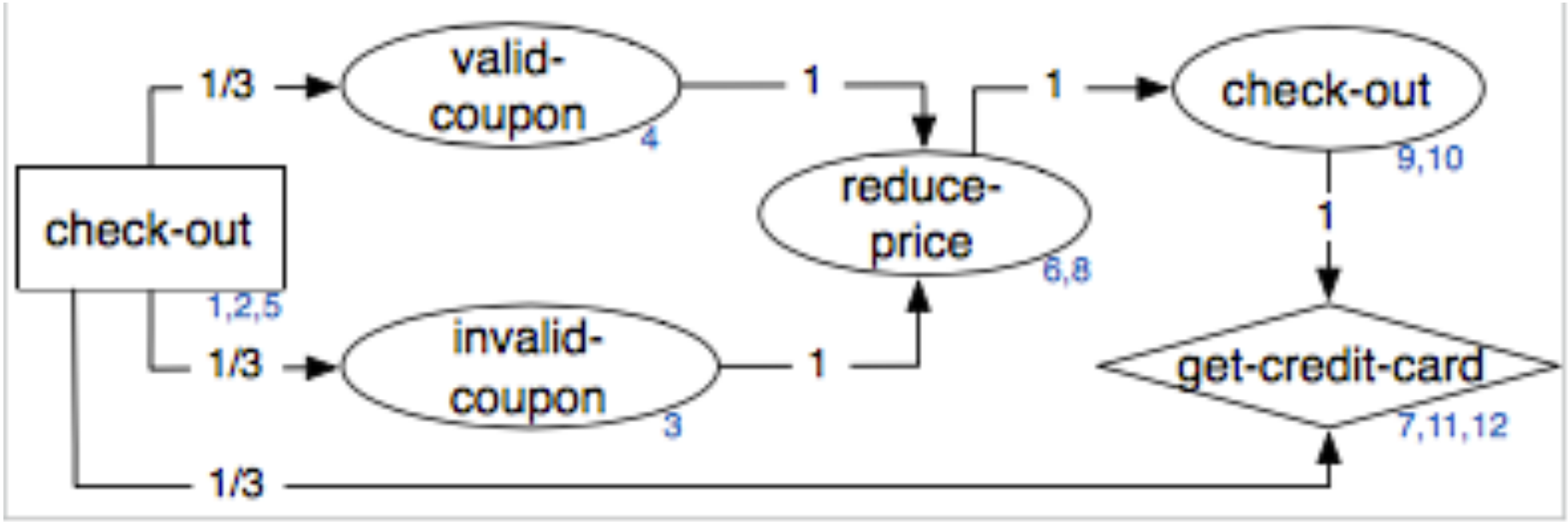
- Coarsen the refined inferred model
  - Search for vertices that didn't need to be split by the refine heuristic and merge them

- The coarsened inferred model satisfies all of the invariants. (It is the final inferred model.)

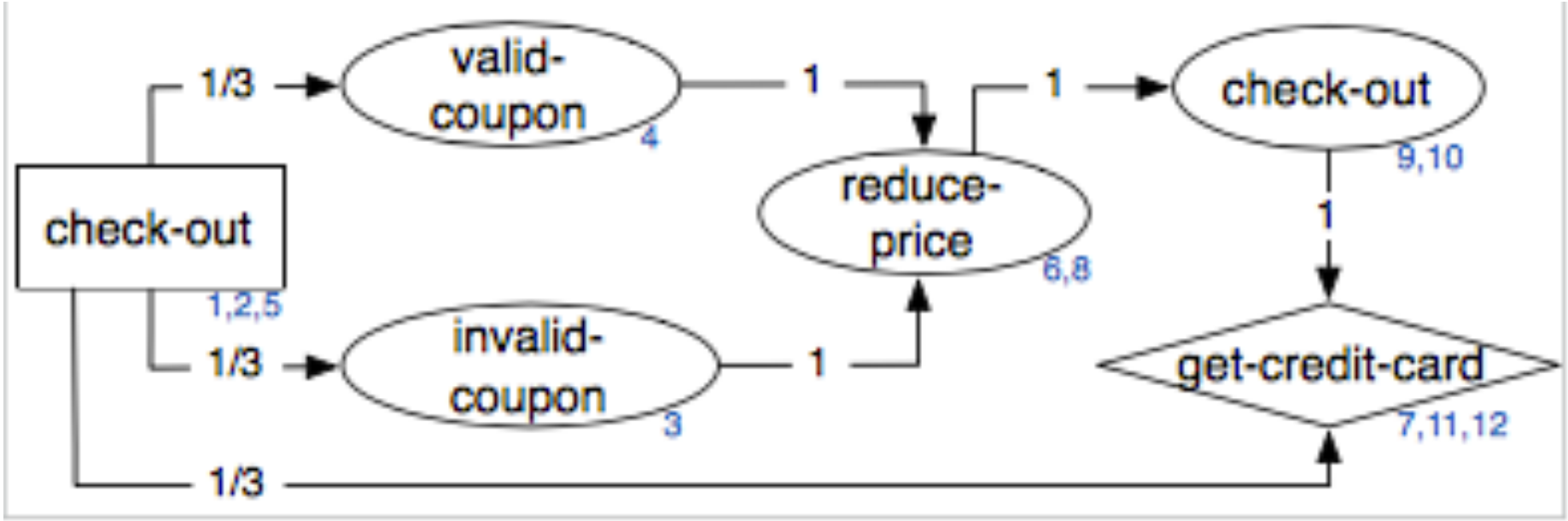
Shopping cart: Coarsened model



Shopping cart: Final model

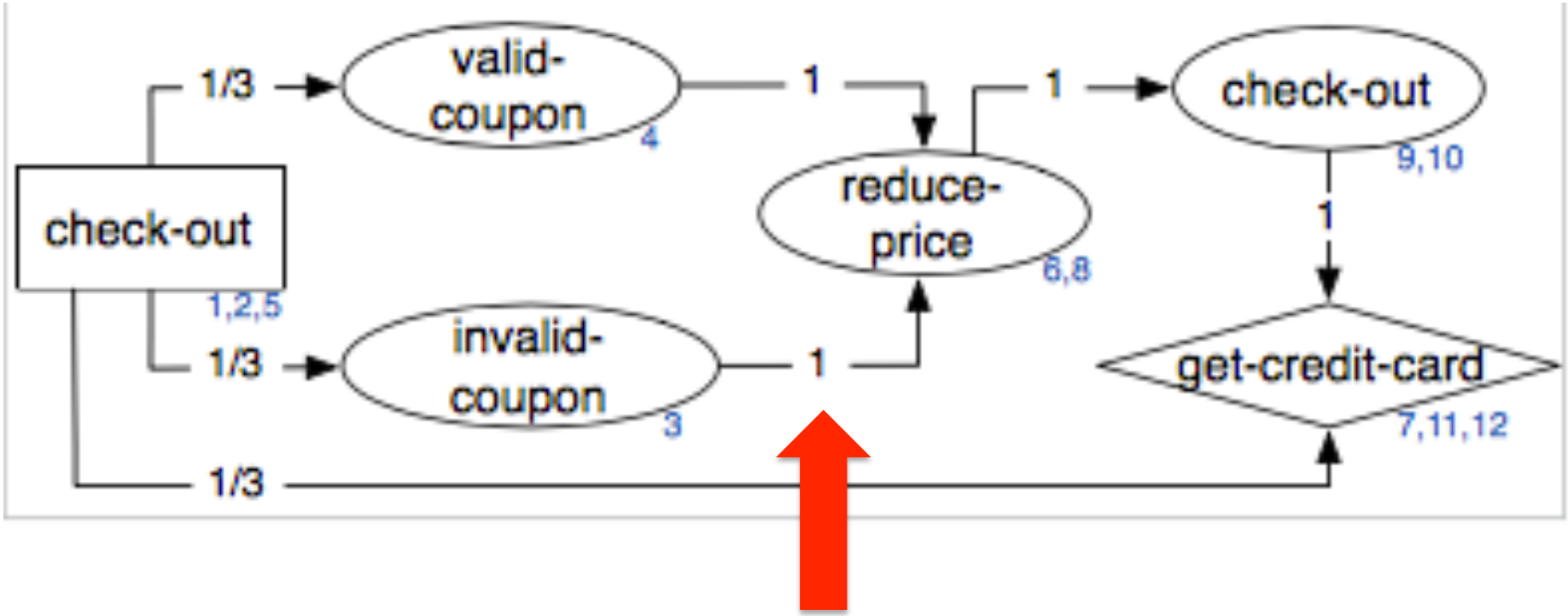


Shopping cart: Final model



Does the inferred model illustrate any unintended behavior (i.e. a bug)?

Shopping cart: Final model



Does the inferred model illustrate any unintended behavior (i.e. a bug)? **YES**

Challenges for model inference

- How does the selection of the event sequence set affect the final model? affect performance?
- How does the parameterization of the model inference algorithm affect the final model?
- How do you compare/contrast (or diff) two inferred models?
- How to support other high-level language features such as concurrency, real-time constraints, …?

Learning from system traces

- Logs, e.g., Synoptic, InvariMint

https://www.cs.ubc.ca/~bestchai/papersinvarimint_icse13.pdf

- Counterexample paths, e.g., libalf: Automata learning framework

http://libalf.informatik.rwth-aachen.de

- Usage scenarios, e.g.,

  https://dl.acm.org/doi/pdf10.1145/1656250.1656252

- …

Homework 3: Overview

Due: Tuesday November 30, 11:59 PM (a little before midnight)

New branch v2.0.0:

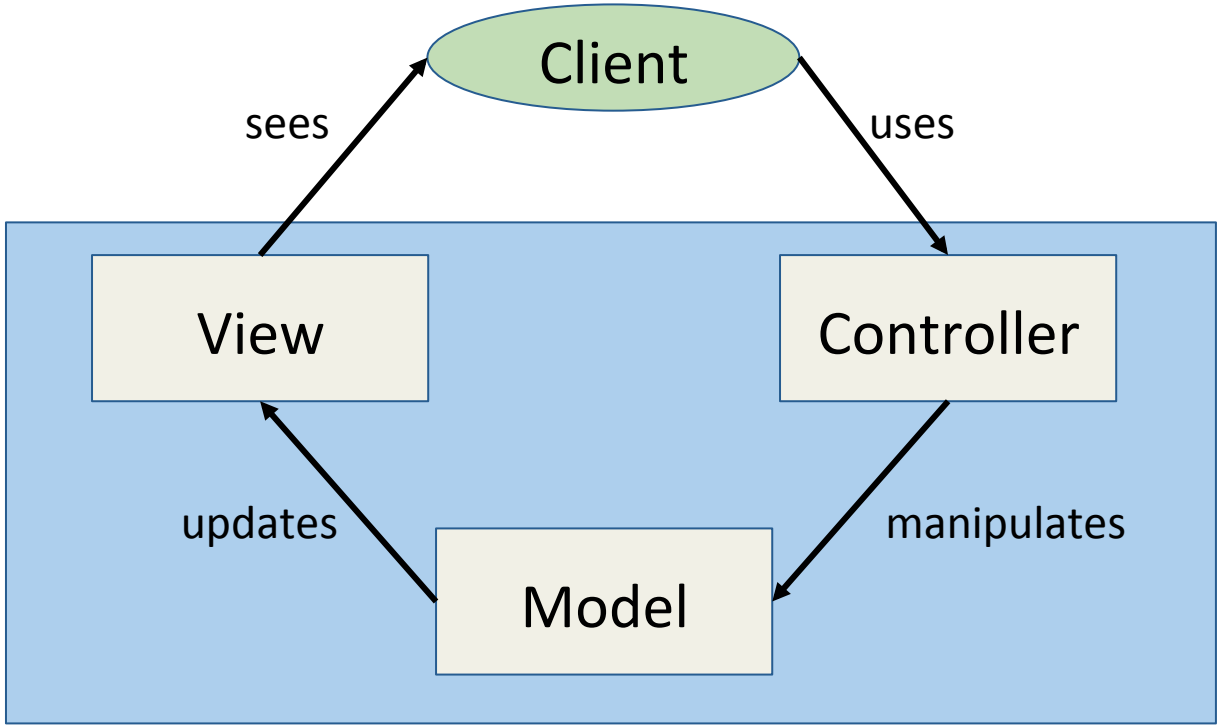
- The RowGameModel class has encapsulated the player and movesLeft fields.
- That class also is using the Player enum type for type safety of the player field.
- The RowGameGUI class is applying the Composite design pattern.
- The test suite updated the existing testNewGame test case and added new test cases for testLegalMove and testIllegalMove.

Homework 3: What to do

1. The RowGameModel class should apply the Observer design pattern.
2. The RowGameController class should apply either the Strategy or Template Method design pattern.
3. In a Java IDE, your project should build, run, and be debugged.

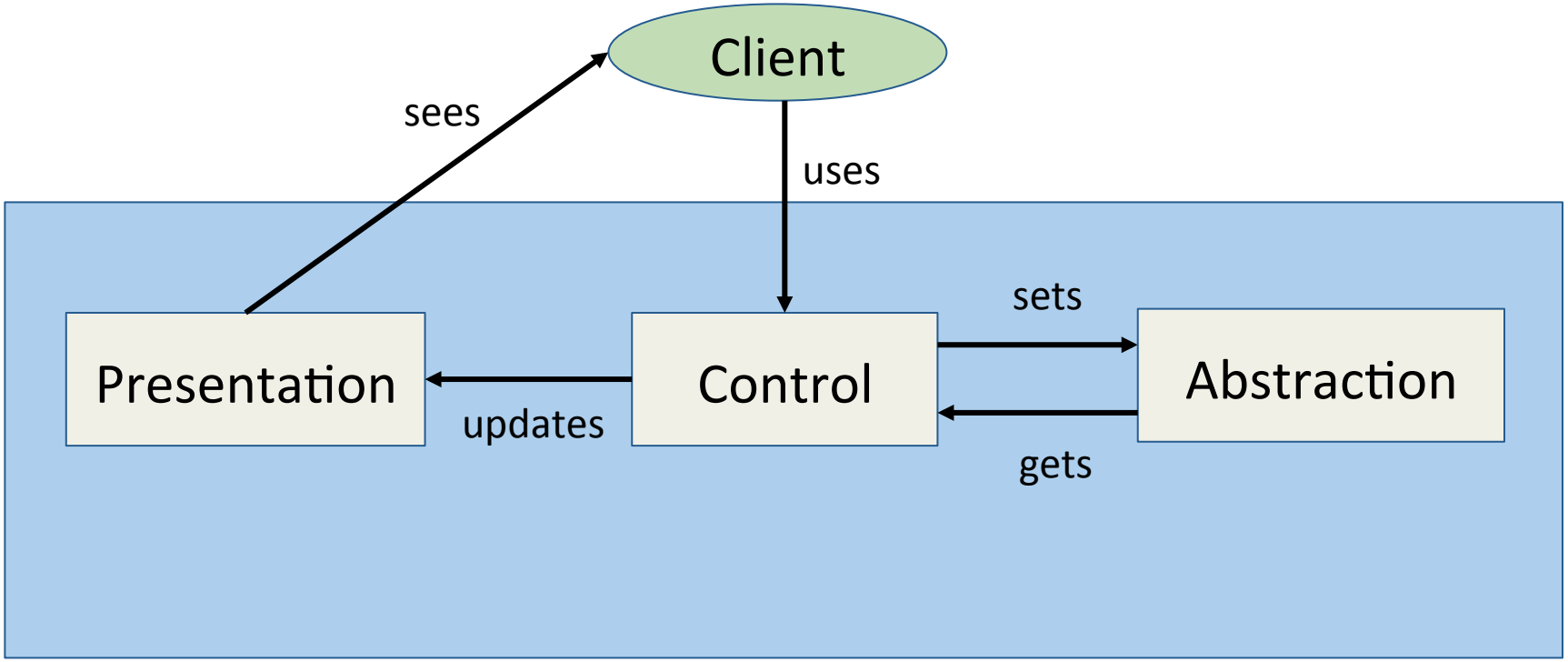
NOTE) There should be git commit messages about the above.

Architecture pattern:
MVC (Model View Controller)



Separates data representation (Model),
visualization (View), and client interaction (Controller)

Architecture pattern:
PAC (Presentation Abstraction Control)



Separates data representation (Abstraction),
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https://en.wikipedia.org/wiki/Presentation%E2%80%93abstraction%E2%80%93control

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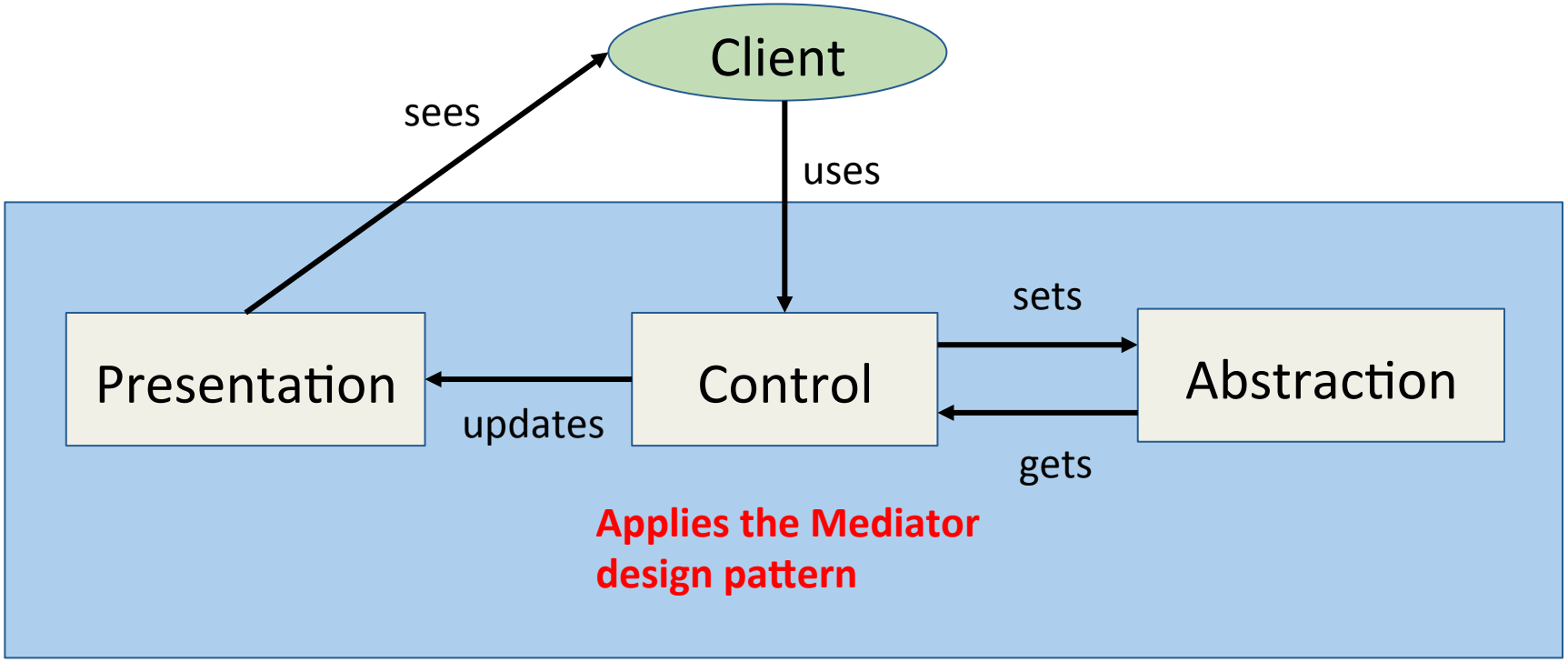

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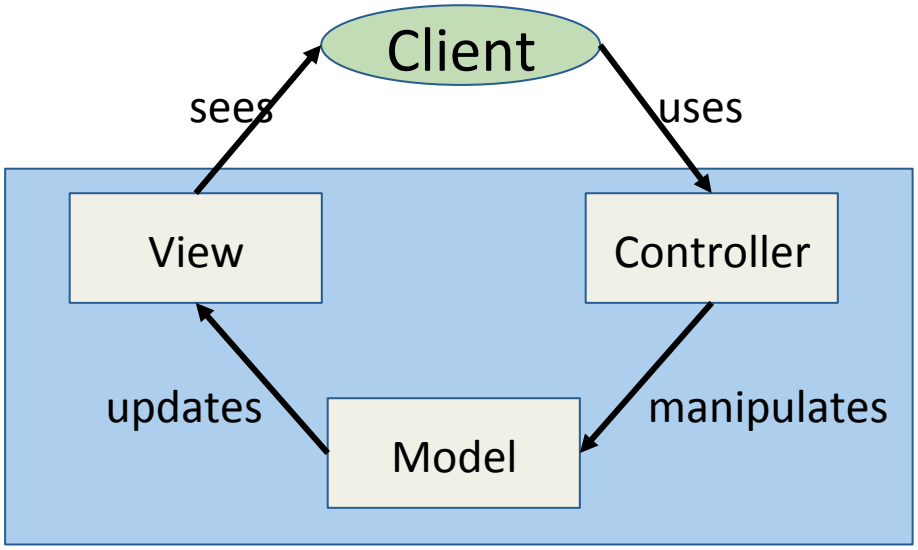
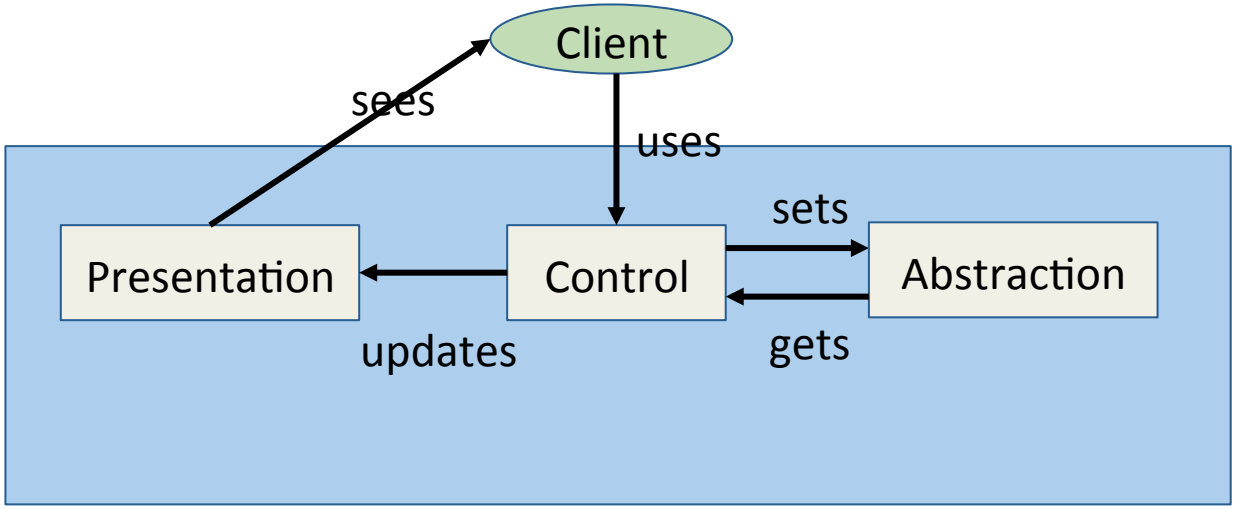
Which architecture?

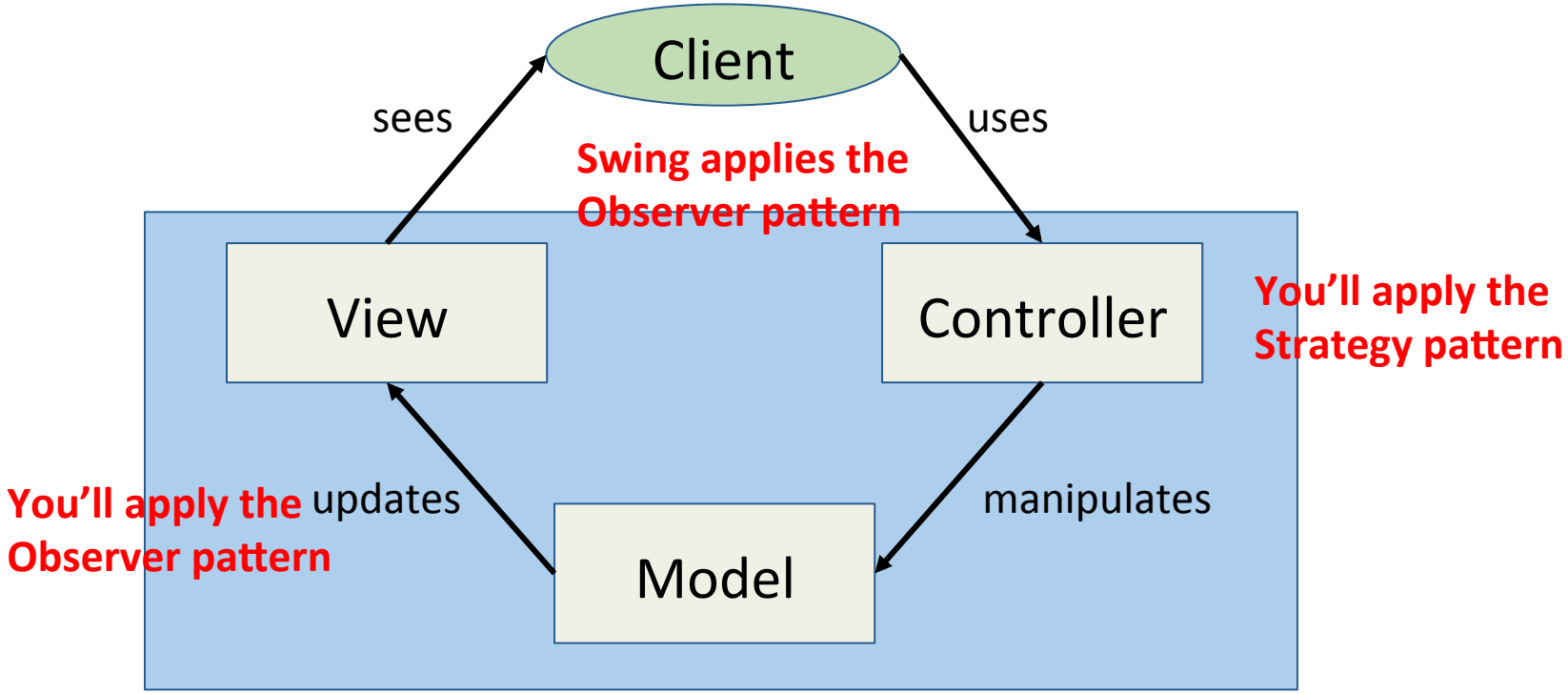
MVC:



PAC:



Design patterns:
Observer and Strategy



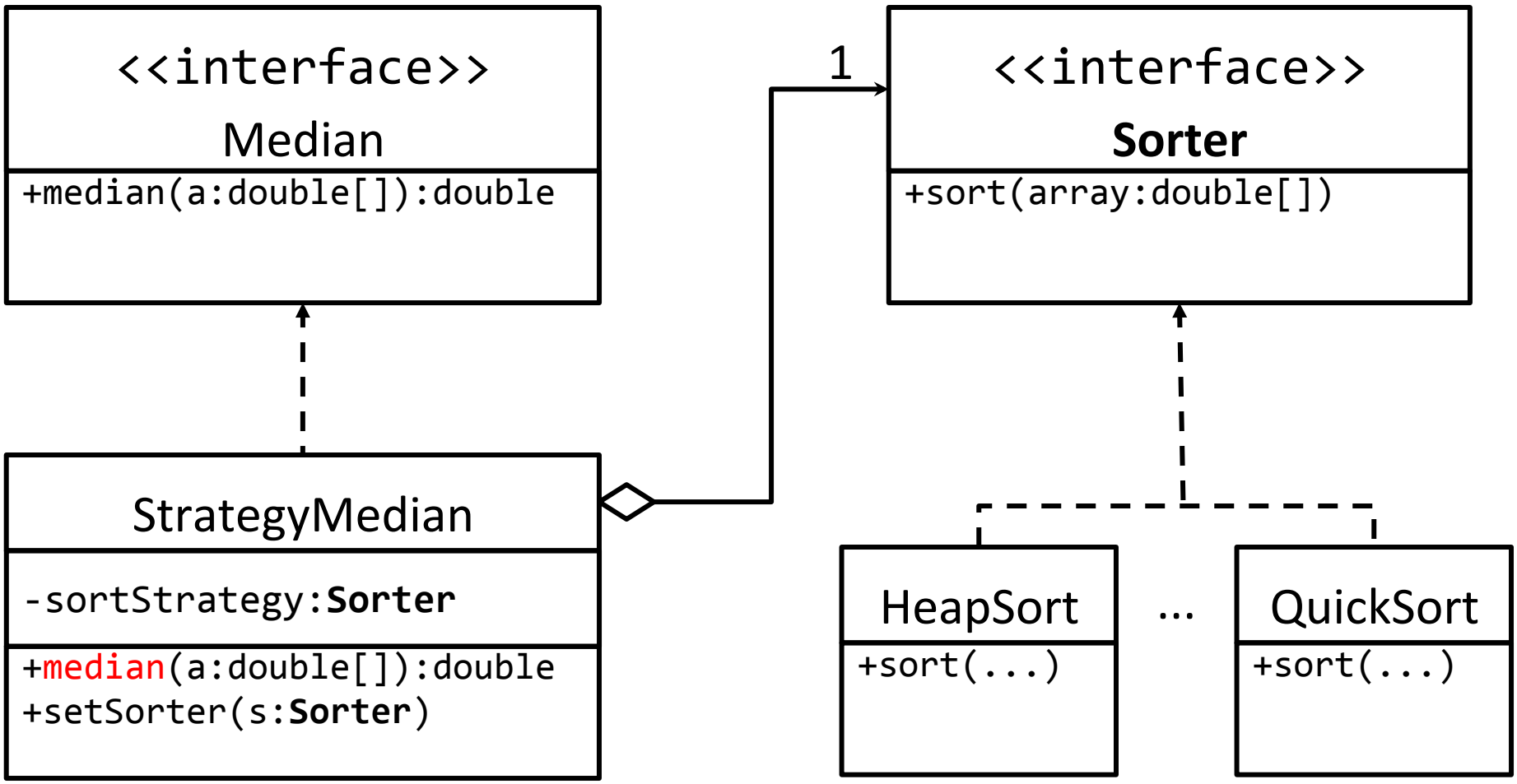
Separates data representation (Model),
visualization (View), and client interaction (Controller)

RowGameController:
Supporting different row game rules

- Different row game rules:
  - Three in a row
  - Tic tac toe

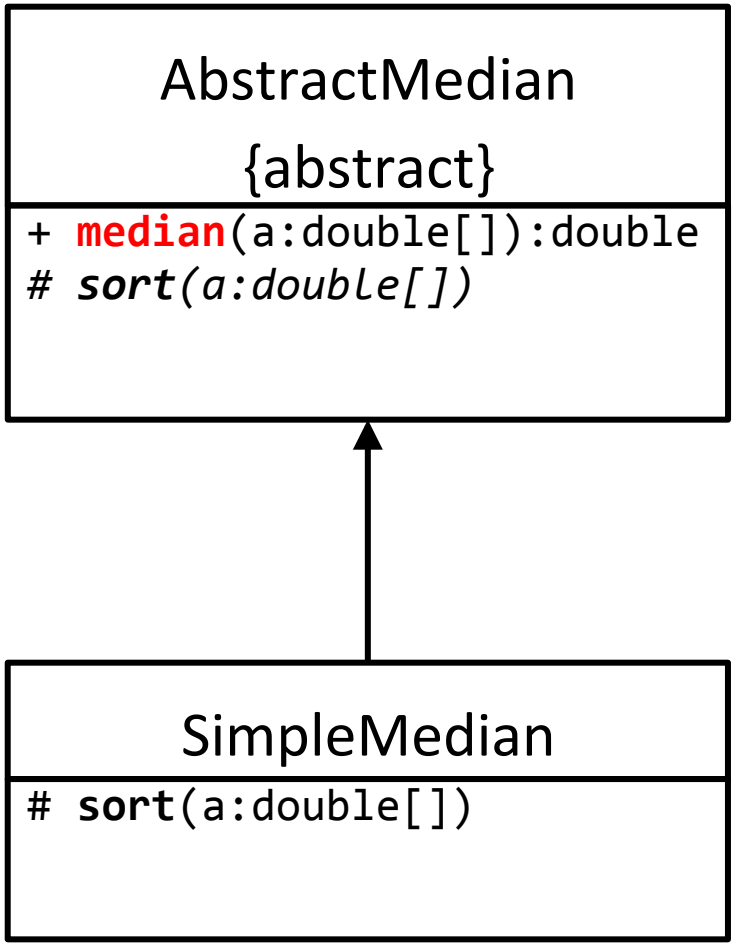
- Two possible solutions:
  - Strategy design pattern
  - Template method design pattern

Strategy design pattern: RowGameController



"median" delegates the sorting of the array to a "sortStrategy"

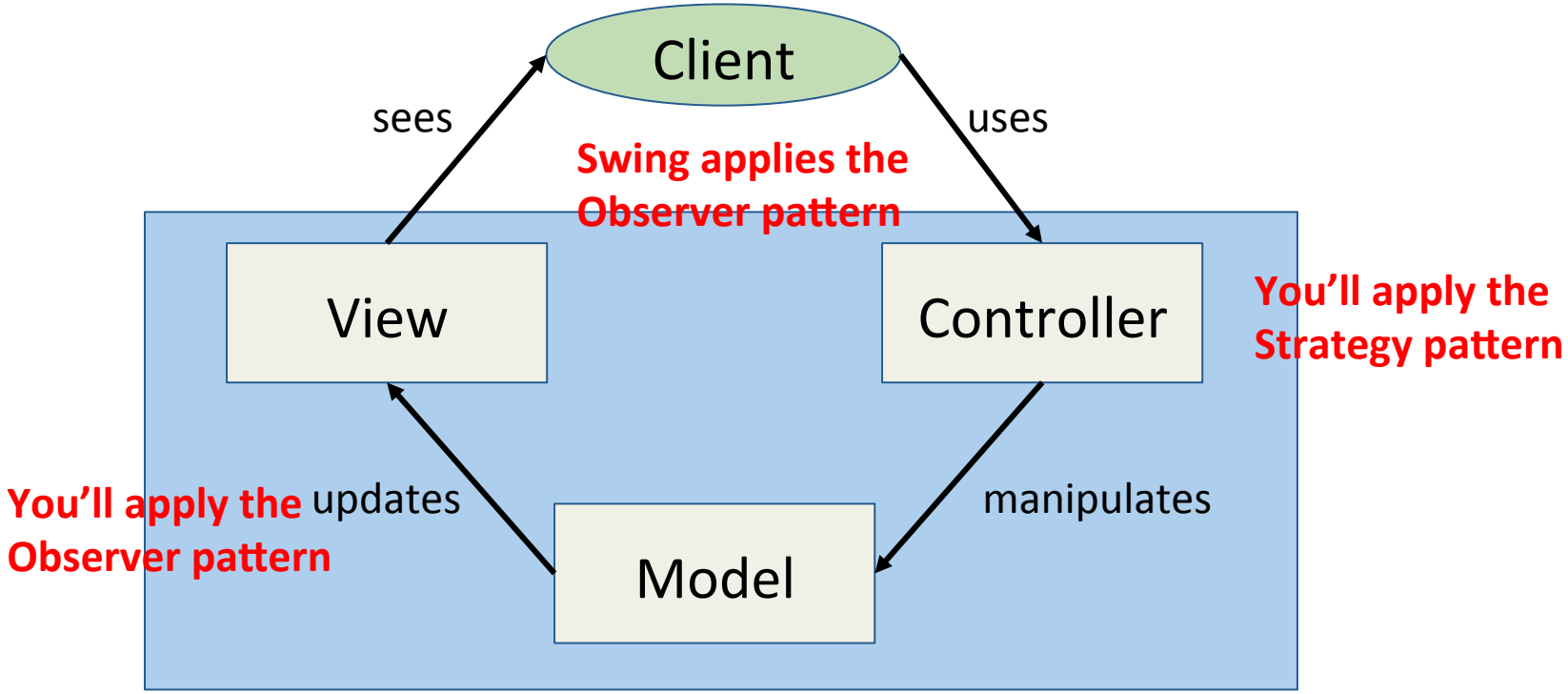
Template method design pattern: RowGameController



Should the median method be final?

- The template method (**median**) implements the algorithm but leaves the **sorting** of the array undefined.
- The concrete subclass only needs to implement the actual **sorting**.

Design patterns:
Observer and Strategy



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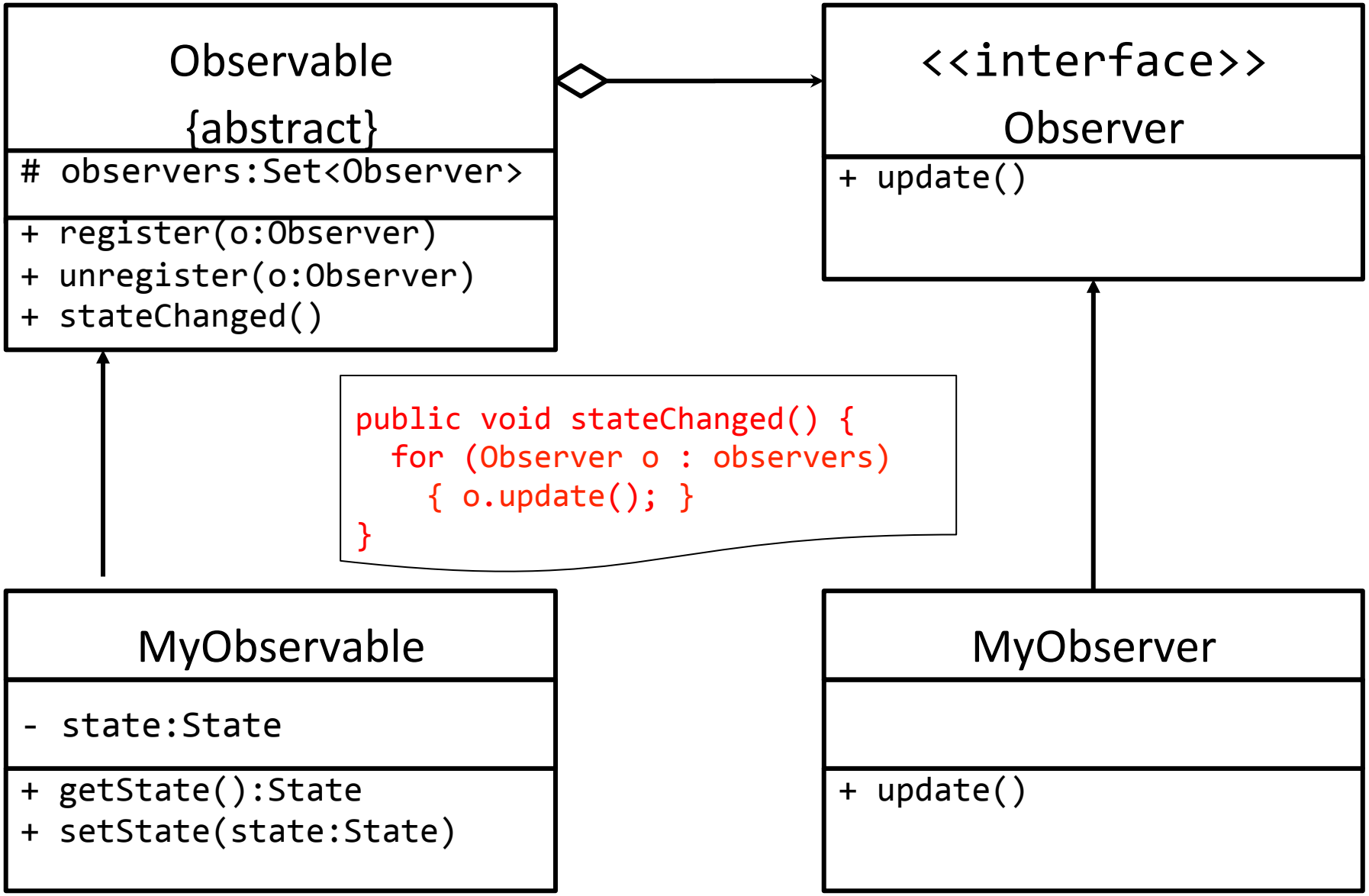
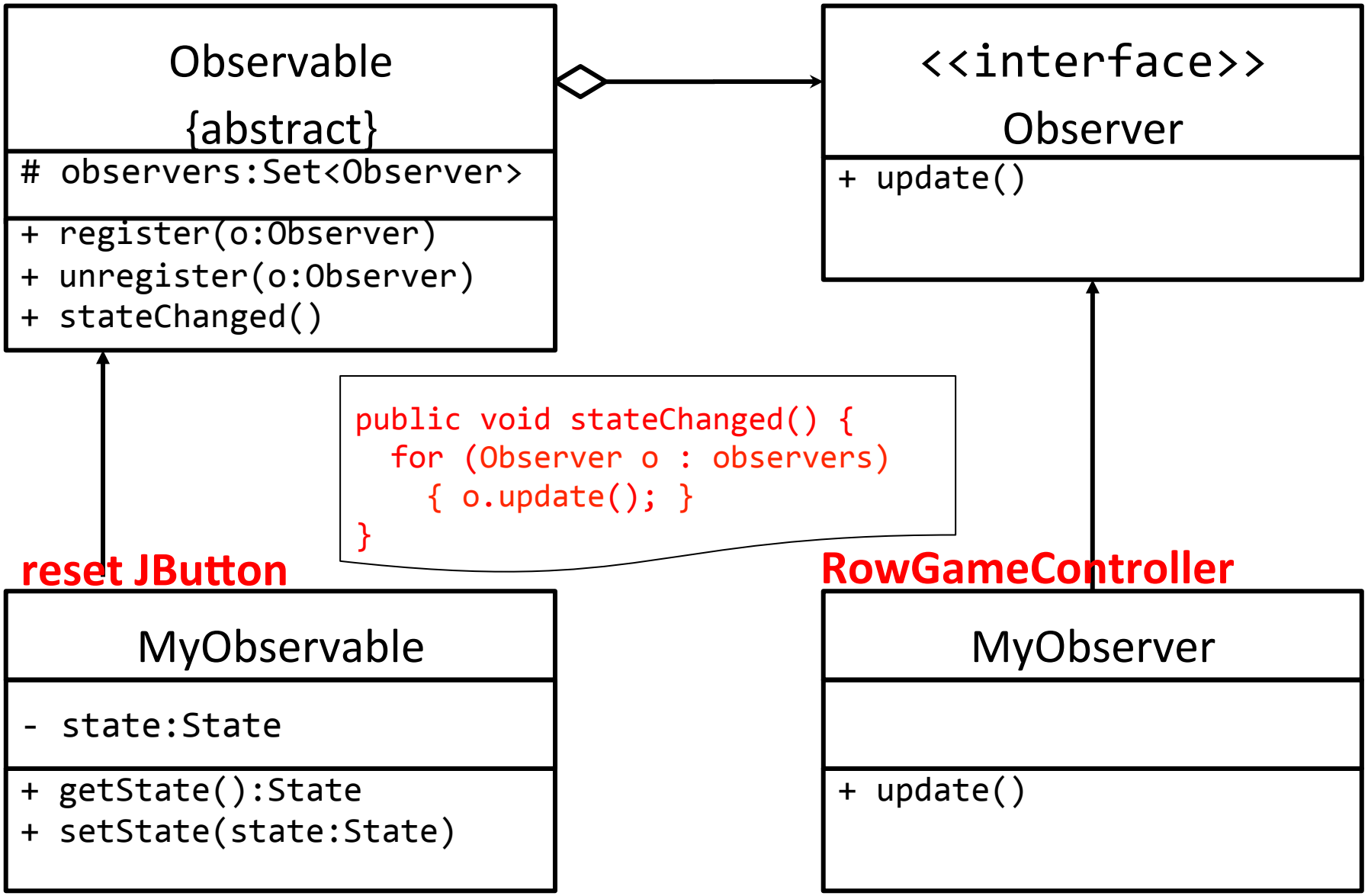
Observer pattern



// For the setState method, use the stateChanged method

Observer pattern: Reset JButton and RowGameController

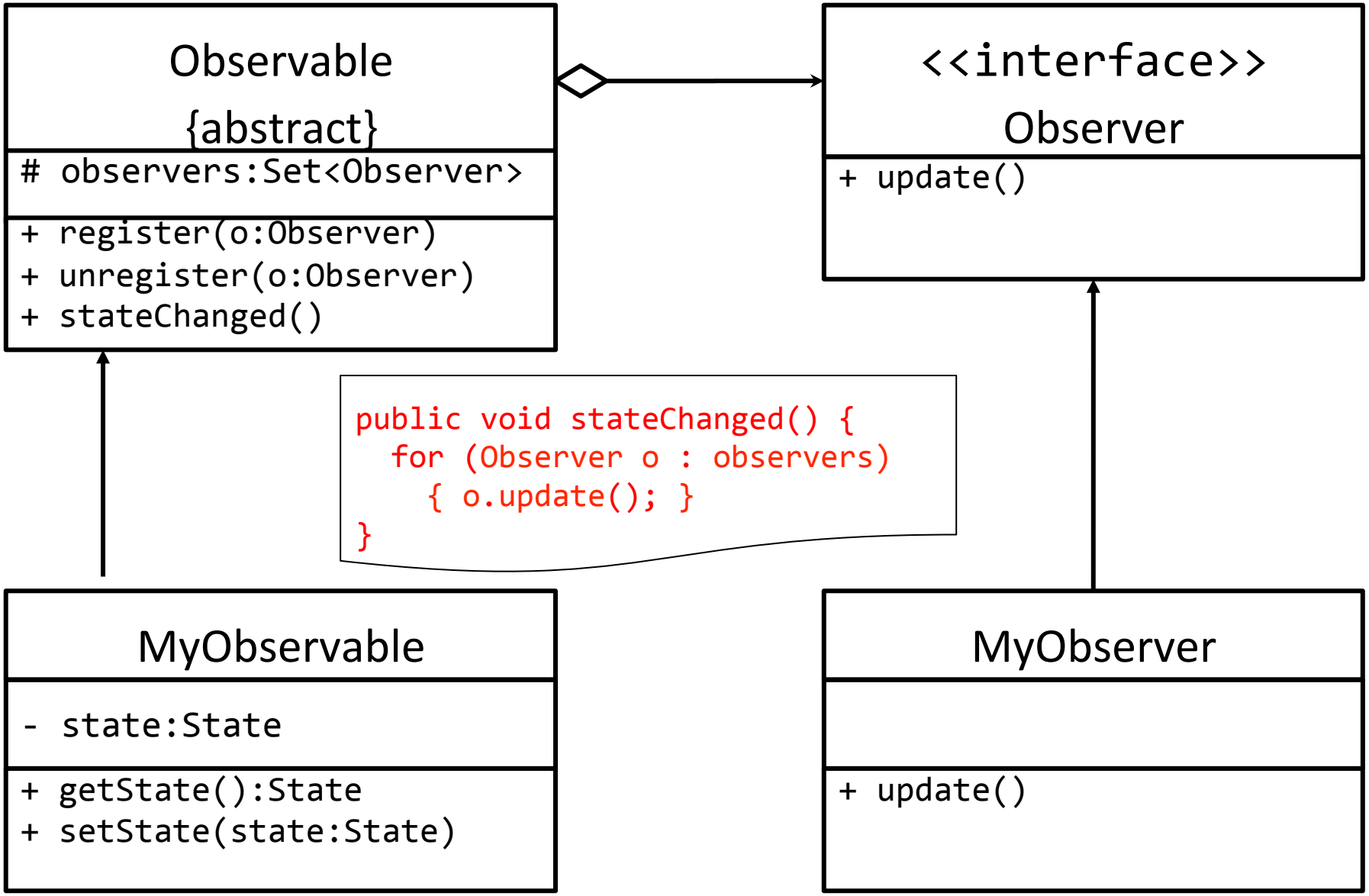


// For the setState method, use the stateChanged method

Learn by example

- https://docs.oracle.com/en/java/javase/14/docs/api/java.desktop/javax/swing/JButton.html
- https://docs.oracle.com/en/java/javase/14/docs/api/java.desktop/javax/swing/AbstractButton.html
- https://docs.oracle.com/en/java/javase/14/docs/api/java.desktop/java/awt/event/ActionListener.html

Observer pattern



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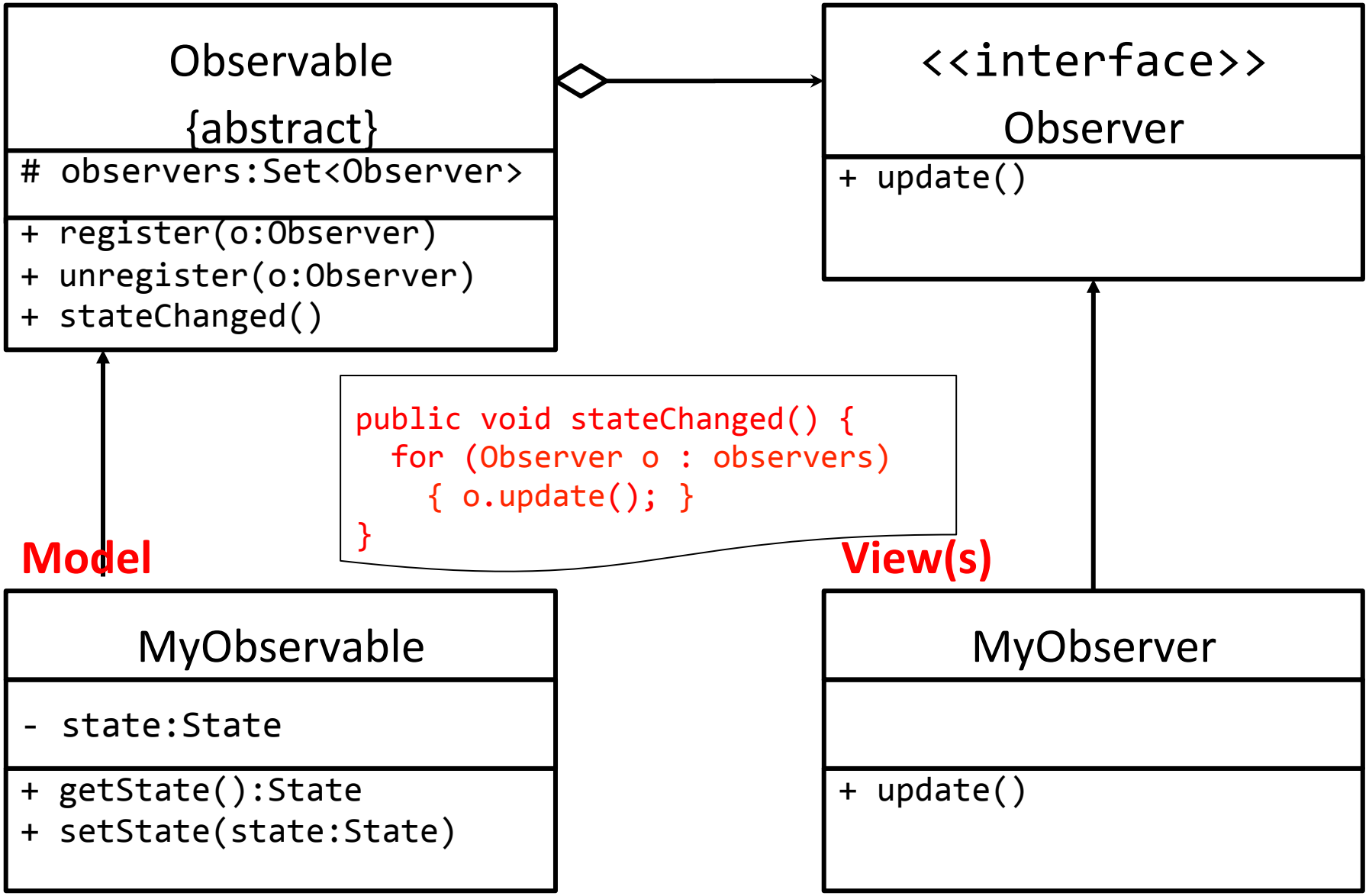
Observer pattern: Model and its View(s)



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Learn from user documentation

- https://docs.oracle.com/en/java/javase/14/docs/api/java.desktop/java/beans/PropertyChangeSupport.html (In our case, we'll be using another design pattern called Adapter.)

- https://docs.oracle.com/en/java/javase/14/docs/api/java.desktop/java/beans/PropertyChangeListener.html