EECS498-008
Formal Verification of Systems Software

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A state is an assignment of values to variables

```
datatype Card = Shelf | Patron(name:
string)
datatype Book = Book(title: string)
type Variables = map<Book, Card>
```

The state space is the set of possible assignments.

The Martian: Shelf
Snow Crash: Shelf

The Martian: Shelf
Snow Crash: Jon

~~The Martian: Jon~~
~~Snow Crash: Jon~~

The Martian: Manos
Snow Crash: Jon

A state machine definition

```
datatype Card = Shelf | Patron(name:
string)
datatype Book = Book(title: string)
type Variables= map<Book, Card>
```

```
predicate Init(v: Variables) {
  forall book | book in v :: v[book] == Shel
}
predicate CheckOut(v : Variables, v’ : Variables, book: Book, name:
string) {
  && book in v
  && v[book] == Shelf
  && (forall book | book in v :: v[book] != Patron(name))
  && v’ == v[book := Patron(name)]
}
```

enabling condition

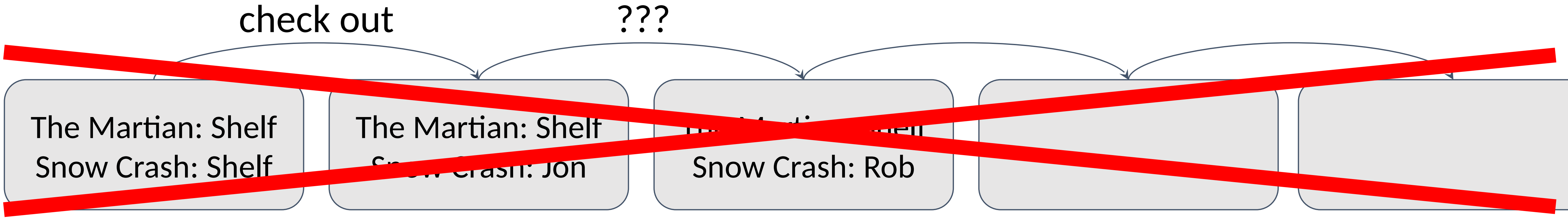
“update”

```
predicate CheckIn(v : Variables, v’ : Variables, book: Book, name: string)
{
  && book in v
  && v[book] == Patron(name)
  && v’ == v[book := Shelf]
}
predicate Next(v: Variables, v’: Variables) {
  || (exists book, name :: CheckOut(v, v’, book, name))
  || (exists book, name :: CheckIn(v, v’, book, name))
}
```

Nondeterministic definition

A **behavior** is the set of **all possible** executions

```
predicate CheckOut(v, v’, book, name) {
  && book in v
  && v[book] == Shelf
  && (forall book | book in v :: v[book] !=
Patron(name))
  && v’ == v[book := Patron(name)]
}
predicate CheckIn(v, v’, book, name) {
  && book in v
  && v[book] == Patron(name)
  && v’ == v[book := Shelf]
}
```



State machine strengths

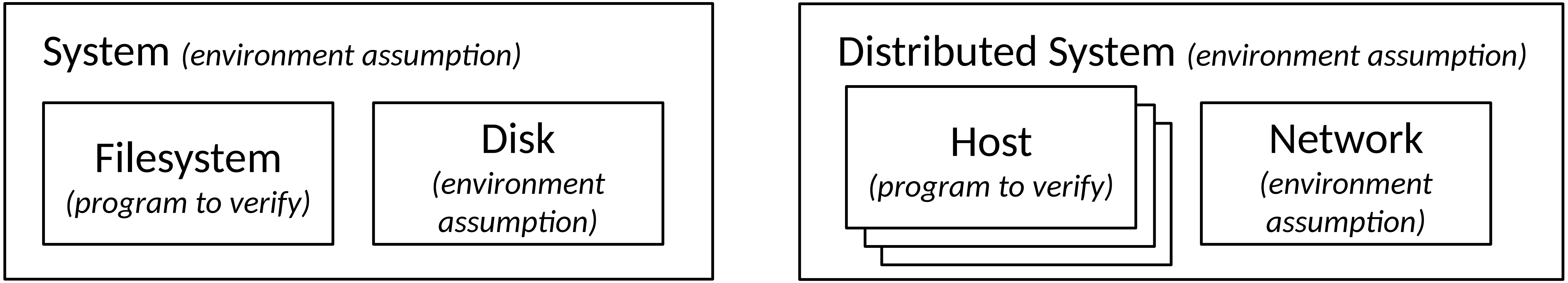
- Abstraction
  - States can be abstract
    - Model an infinite map instead of an efficient pivot table
  - Next predicate is nondeterministic:
    - Implementation may only select some of the choices
    - Can model Murphy’s law (e.g. crash tolerance) or an adversary

State machine strengths

- Abstraction
- Asynchrony
  - Each step of a state machine is conceptually atomic
  - Interleaved steps capture asynchrony: threads, host processes, adversaries
  - Designer decides how precisely to model interleaving; can refine/reduce

State machine strengths

- Abstraction
- Asynchrony
- Environment
  - Model a proposed program with one state machine (verified)
  - Model (adversarial) environment with another (trusted)
  - Compound state machine models their interactions (trusted)

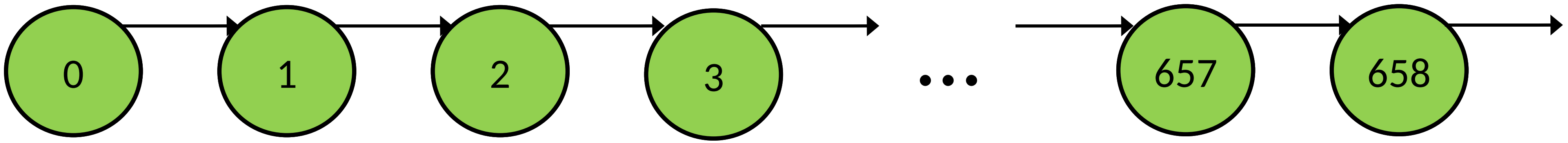


Chapter 4: Proving properties

Expressing a system as a state machine allows us to prove that it has certain properties

- We will focus on safety properties
  - i.e. properties that hold throughout the execution

Basic tool: induction



- Show that the property holds on state 0
- Show that if the property holds on state k, it must hold on state k+1

Let’s prove a safety invariant!

```
predicate Safety(v:Variables) {
  true // TBD
}

lemma SafetyProof()
  ensures forall v :: Init(v) ==> Safety(v)
  ensures forall v, v' :: Safety(v) && Next(v, v') ==> Safety(v')
{
}
```

Base case

Inductive Step

Let’s prove a safety invariant!

Interactive proof development in editor

Bisection debugging,

case analysis,

existential instantiation

Jay Normal Form

As you begin writing more interesting specs, proofs will be nontrivial.

Pull all the nondeterminism into one place, and get a receipt.

image: flickr/afagen CC-by-nc-sa

Jay Normal Form

```
datatype Step =
  | Action1Step( <parameters> )
  | Action2Step( <parameters> )
  ...

predicate NextStep(v: Variables, v’: Variables, step:Step)
{
  match step
    case Action1Step(<parameters>) => Action1(v, v’, <parameters>)
    case Action2Step(<parameters>) => Action2(v, v’, <parameters>)
    ...
}
predicate Next(v: Variables, v’: Variables)
{
    exists step :: NextStep(v, v’, step)
}
```