EECS498-008 Formal Verification of Systems Software

Material and slides created by

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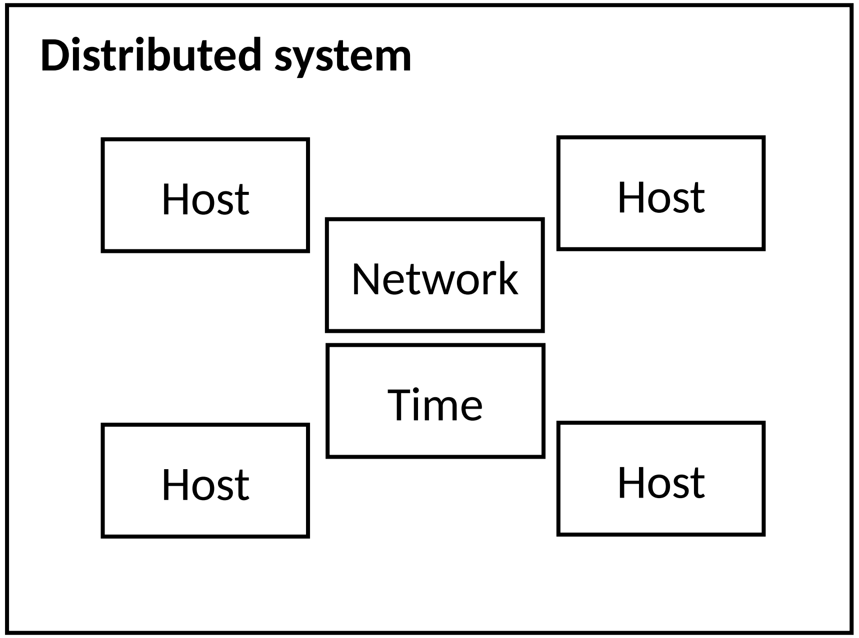
A distributed system is composed of multiple hosts, **a network and clocks**

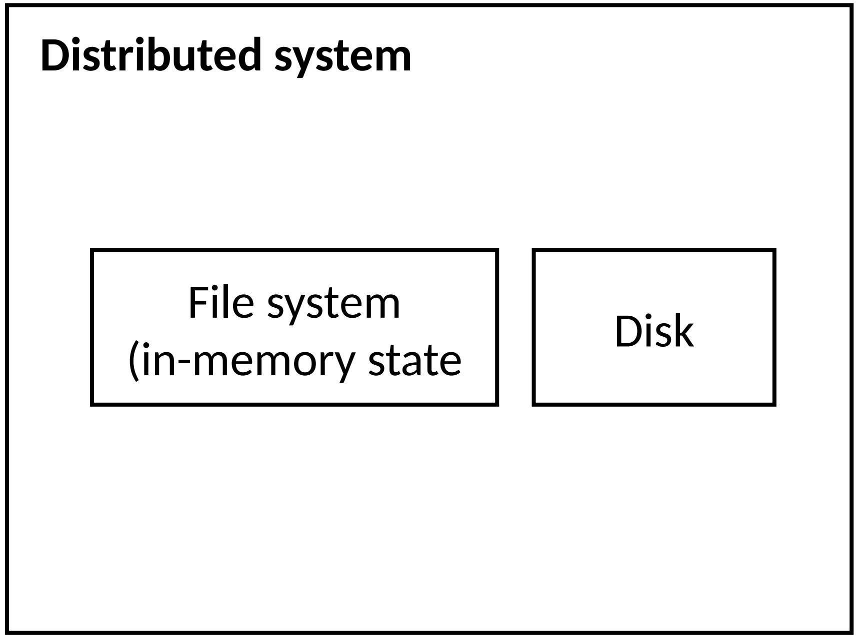


Distributed system: attempt #3

```
module DistributedSystem {
  datatype Variables =
    Variables(hosts:seq<Host.Variables>,
              network: Network.Variables,
              time: Time.Variables)

  predicate Next(v, v', hostid, msgOps: MessageOps, clk:Time) {
    || (&& HostAction(v, v', hostid, msgOps)
        && Network.Next(v, v', msgOps)
        && Time.Read(v.time, clk))
    || (&& Time.Advance(v.time, v'.time)
        && v'.hosts == v.hosts
        && v'.network == v.network)
  }
}
```

A “distributed” system

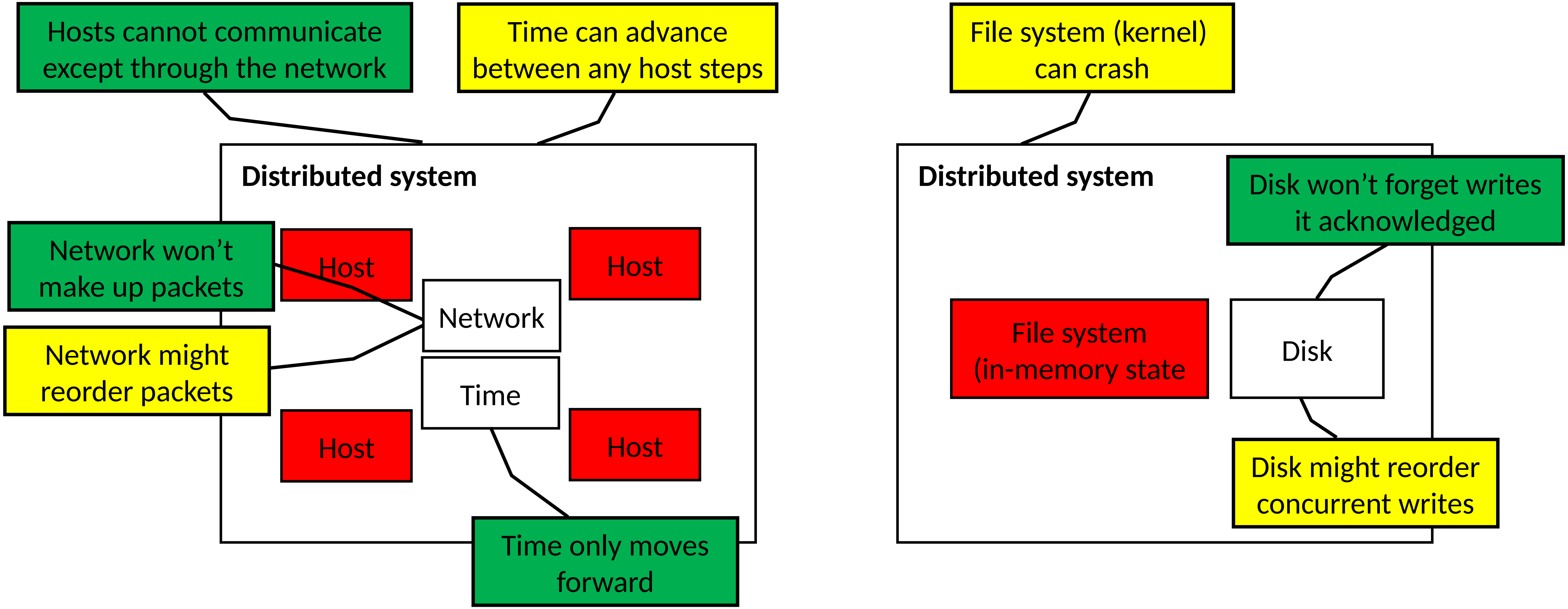



```
module DistributedSystem {
  datatype Variables =
    Variables(fs: FileSystem.Variables,
              disk: Disk.Variables)

  predicate Next(v, v’) {
    || (exists io ::
         && FileSystem.Next(v.fs, v’.fs, io)
         && Disk.Next(v.disk, v’.disk, io)
    || ( // Crash!
         && FileSystem.Init(v’.fs)
         && v’.disk == v.disk
       )
  }
}
```

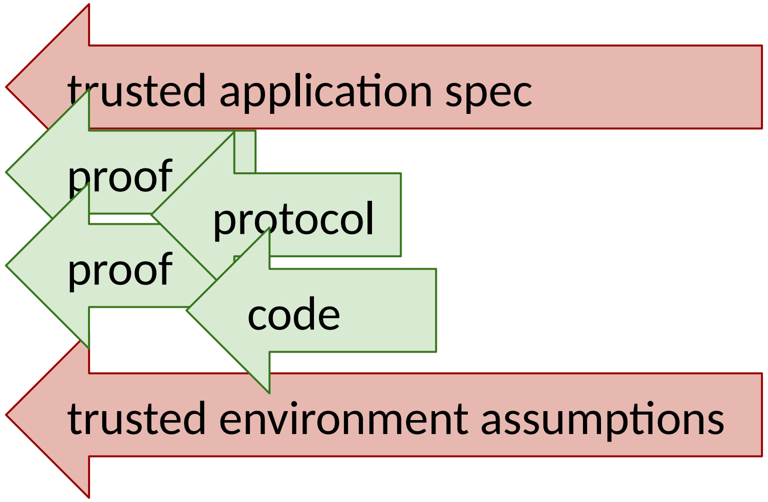
Binding variable

Trusted vs proven



SPECIFICATION: the systems specification sandwich

image: pixabay

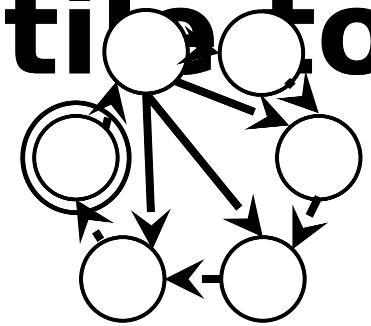


Administrivia

- Midterm went great, congratulations!
- Problem set 3 due on Friday
- Project 1 will be released on Monday
  - Let me know if you can't find teammates
- Midterm evaluations due today!
  - They are **really, really important**
  - If we reach 66%, I'll design custom course stickers
- I'm giving another lecture right after this one, so I have to skip IOH

Chapter 6: Refinement

State machines: a versatile tool

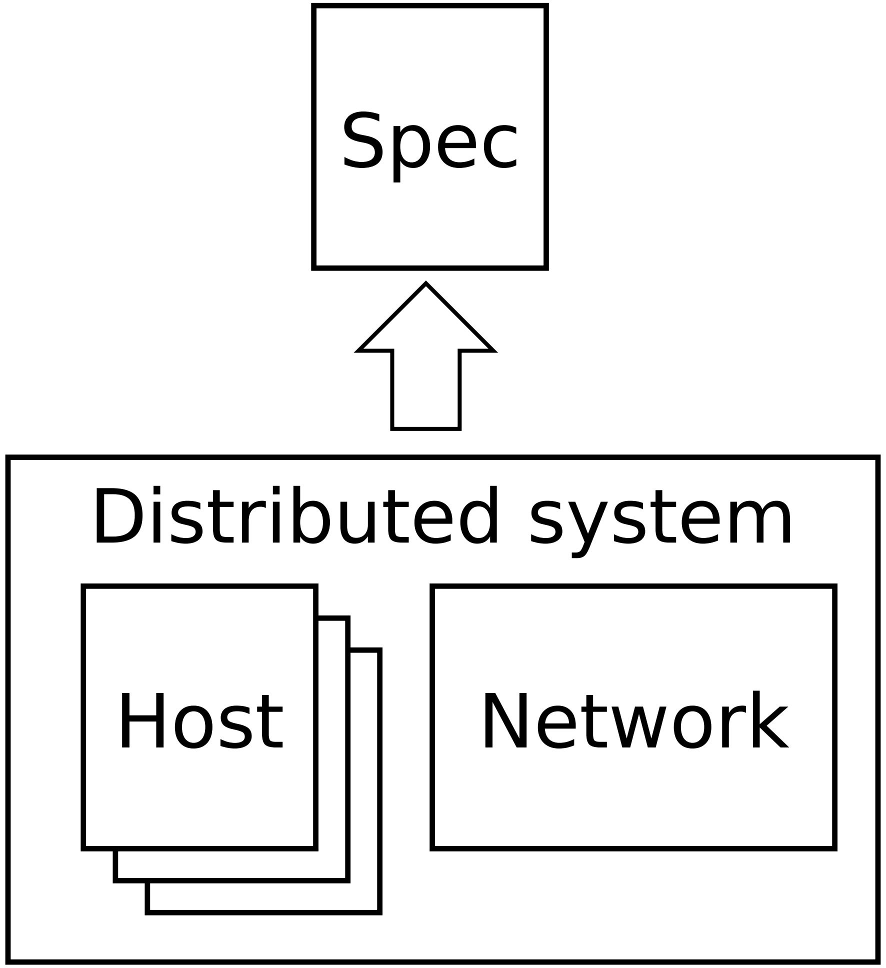


State machines can be used to

- Model the program
- Model environment components
- Model how the system (program+environment) fits together
- Specify the system behavior

Different ways to specify behavior

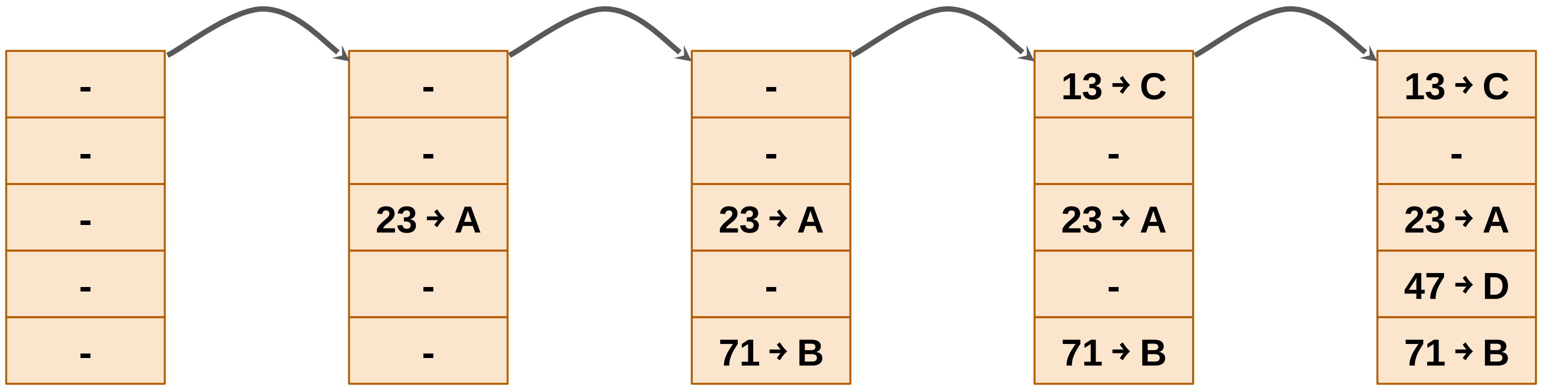
- C-style assertions
- Postconditions
- Properties/invariants
- Refinement to a state machine



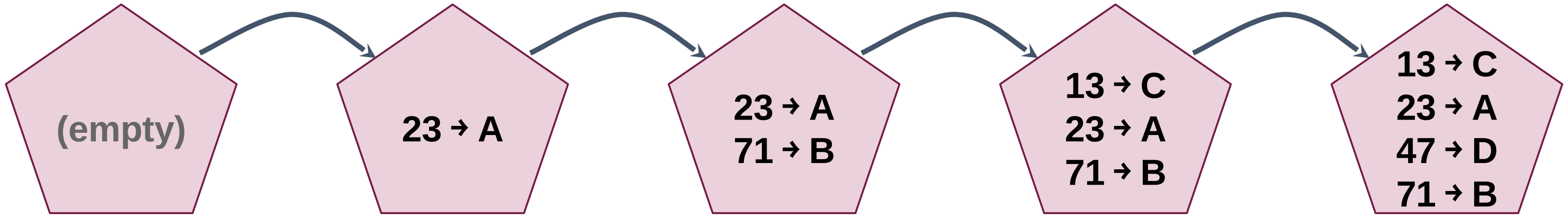
Example: hashtable

```
module HashTable {
  datatype Variables = Variables(tbl:seq<Pair<int, string>>)

  predicate Insert(v:Variables, v':Variables, key:int,
val:string) {
    var free := Probe(v.tbl, key);
    && free.Some?
    && v'.tbl == v.tbl[free.value := Pair(key, val)]
  }
}
```



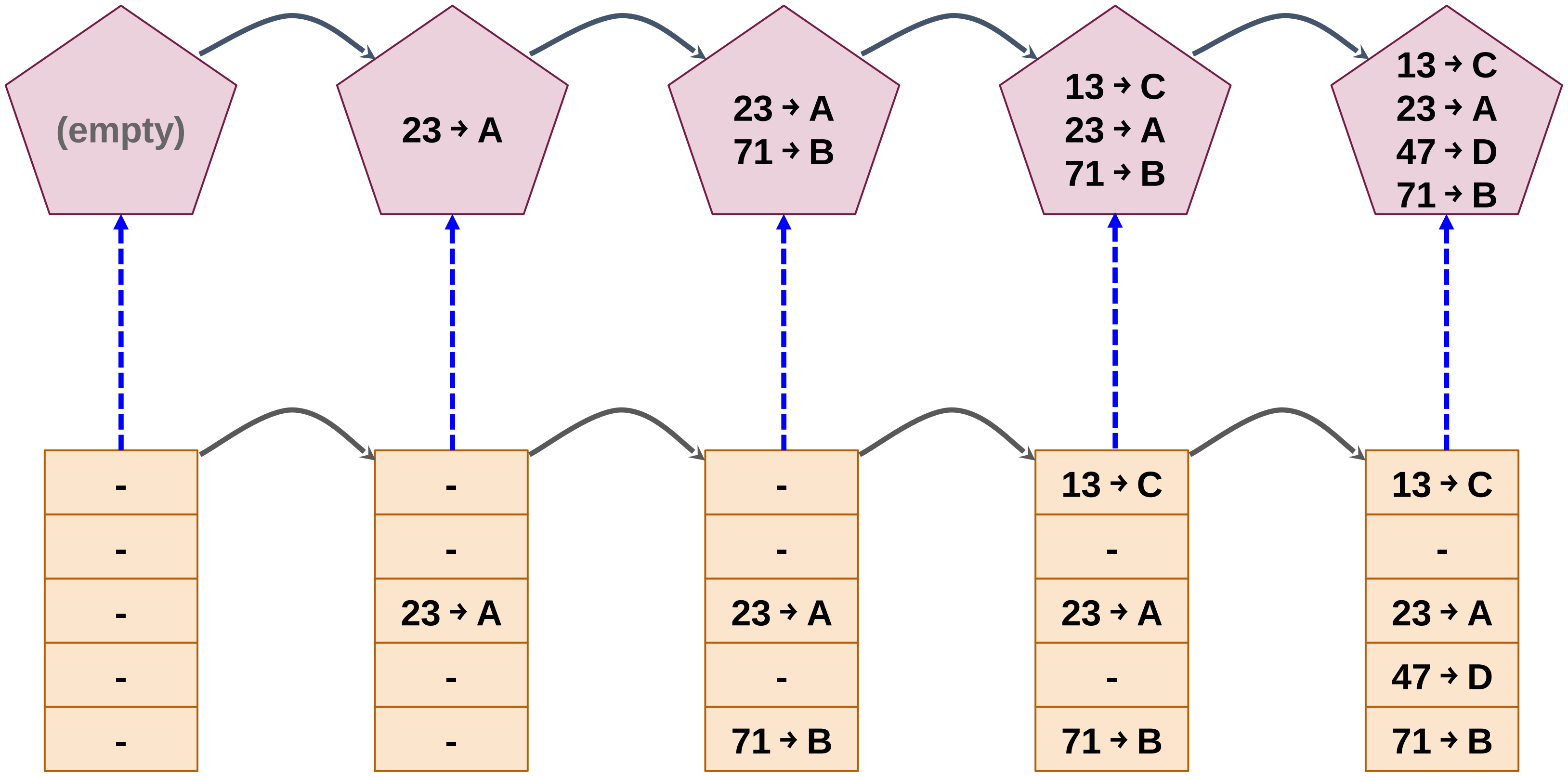
The spec: a simple map




```
module MapSpec {
  datatype Variables = Variables(mapp:map<Key, Value>)

  predicate InsertOp(v:Variables, v':Variables, key:Key,
value:Value) {
    && v'.mapp == v.mapp[key := value]
  }
}
```

Refinement


(empty)
23 → A
23 → A
71 → B
13 → C
23 → A
71 → B
13 → C
23 → A
47 → D
71 → B
-
-
-
-
-
-
-
23 → A
-
-
-
-
23 → A
-
71 → B
13 → C
-
23 → A
-
71 → B
13 → C
-
23 → A
47 → D
71 → B

The benefits of refinement

Refinement allows for good specs

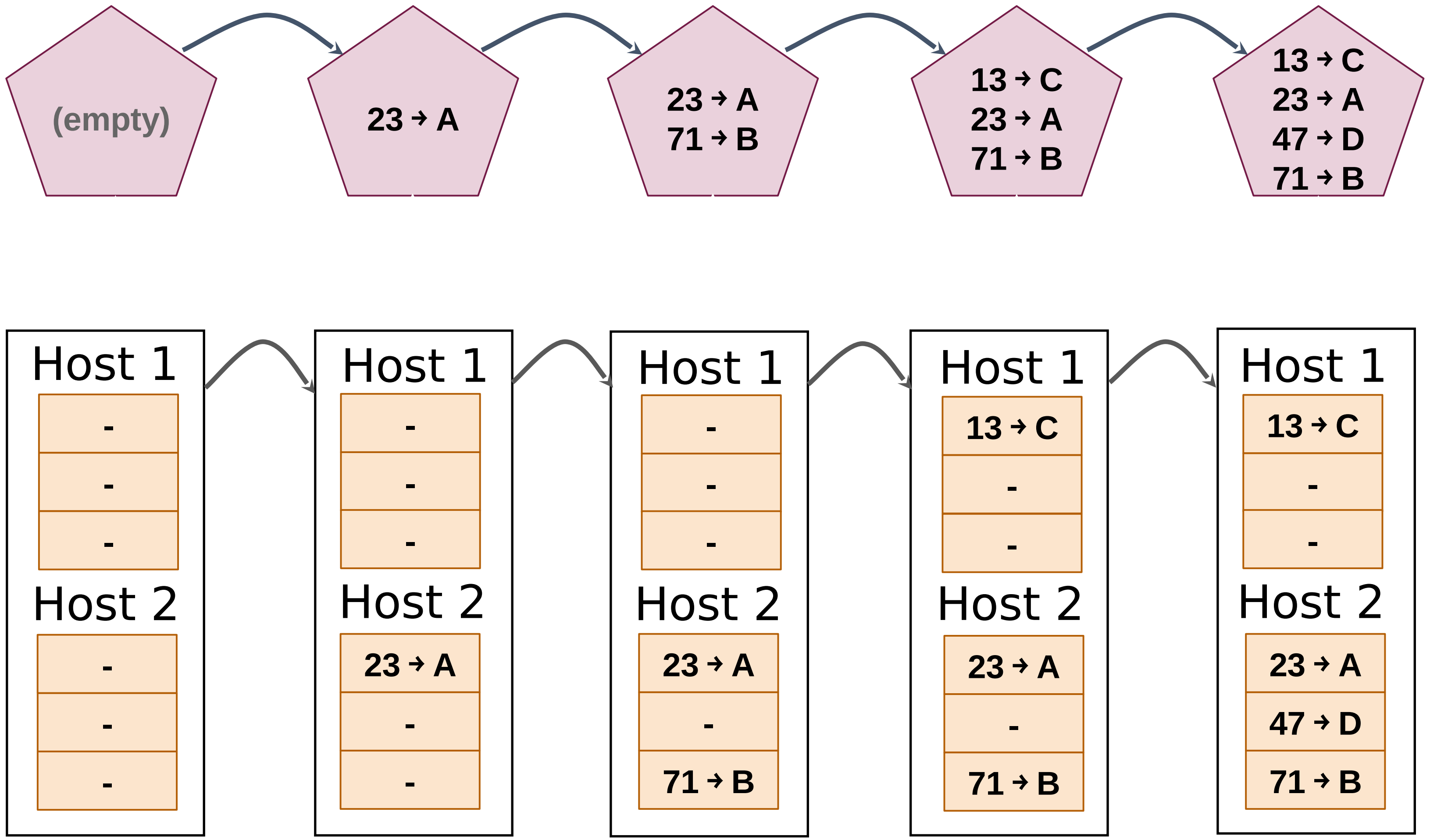
- Abstract: elide implementation details
- Concise: simple state machine
- Complete: better than a “bag of properties”
  - But if you want, you can prove properties about the spec

Refinement is very powerful

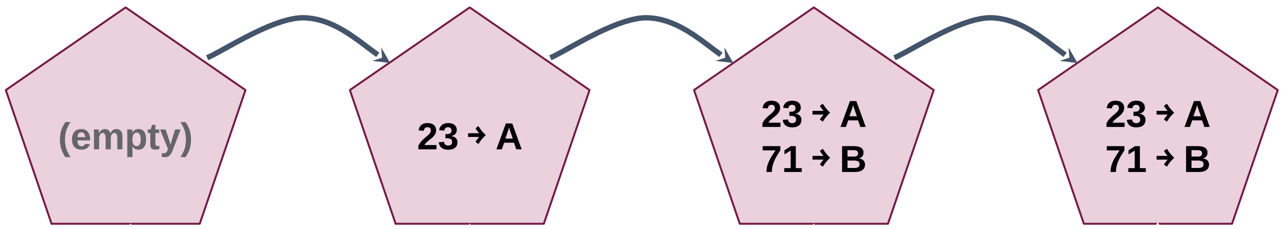
- Can specify systems that are hard to specify otherwise
  - E.g. linearizability

A sharded key-value store

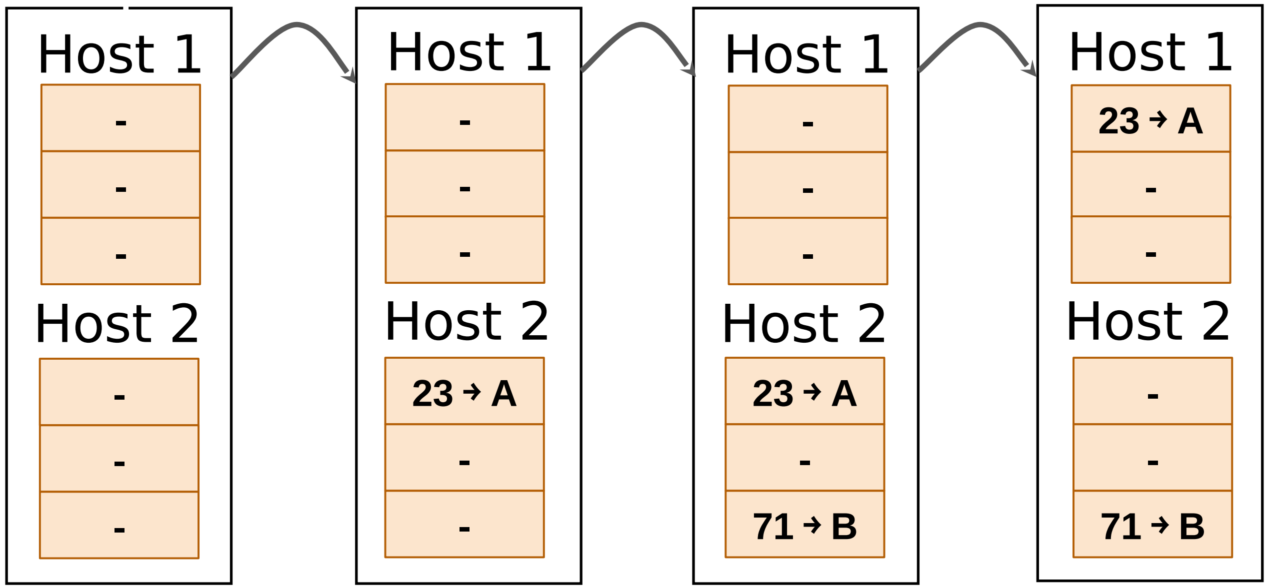
Logically centralized, physically distributed



Stutter steps

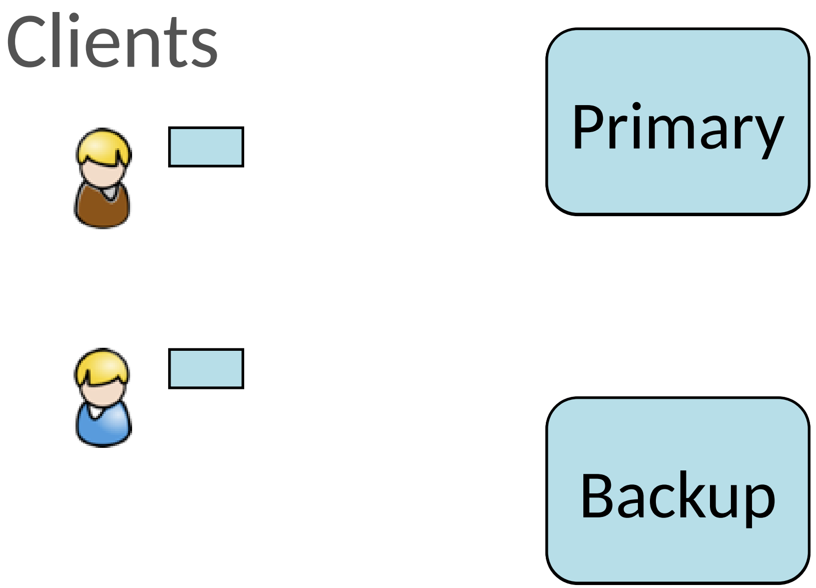


One "stutter" step for the spec

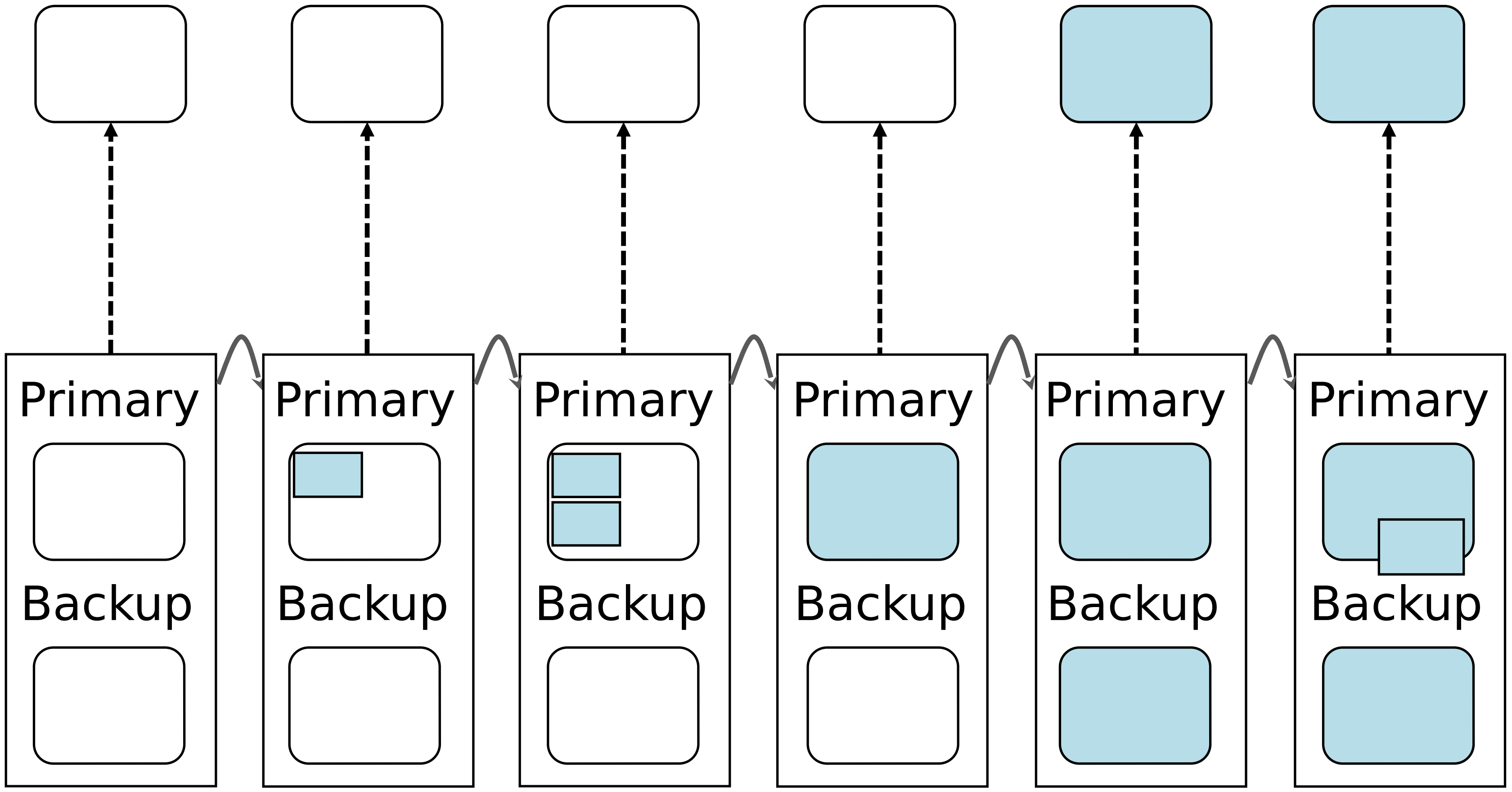


One normal step for the implementation

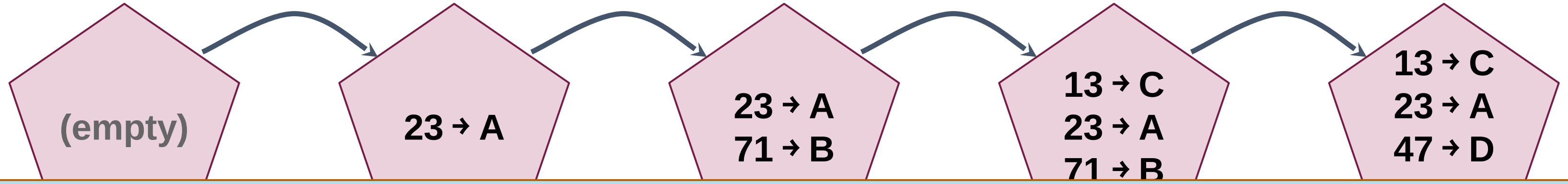
A primary-backup protocol



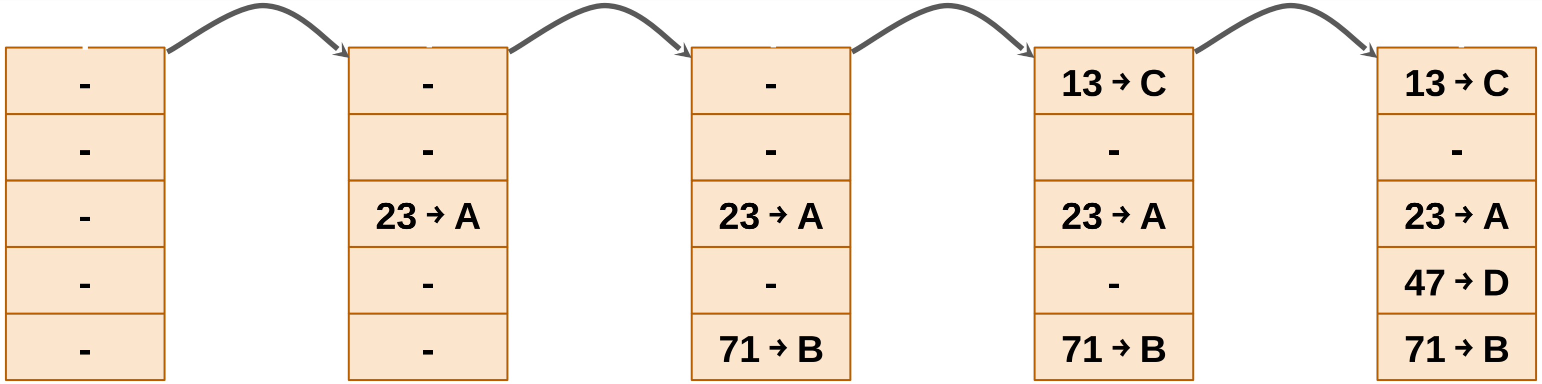
A primary-backup protocol



The interpretation (Abstraction) function




```
function Abstraction(lv:HashTblState) : (hv:MapSpec.Variables)
{
  ...
}
```



A refinement proof

```
function Abstraction(v:Variables) : MapSpec.Variables
predicate Inv(v:Variables)

lemma RefinementInit(v:Variables)
requires Init(v)
ensures Inv(v) // Inv base case
ensures MapSpec.Init(Abstraction(v))  // Refinement base case

lemma RefinementNext(v:Variables, v':Variables)
    requires Next(v, v')
    requires Inv(v)
    ensures Inv(v')  // Inv inductive step
    ensures MapSpec.Next(Abstraction(v), Abstraction(v')) // Refinement inductive step
        || Abstraction(v) == Abstraction(v')                        // OR stutter step
```