COMPUTER SCIENCE & ENGINEERING

EECS498-008
Formal Verification of Systems Software

Material and slides created by

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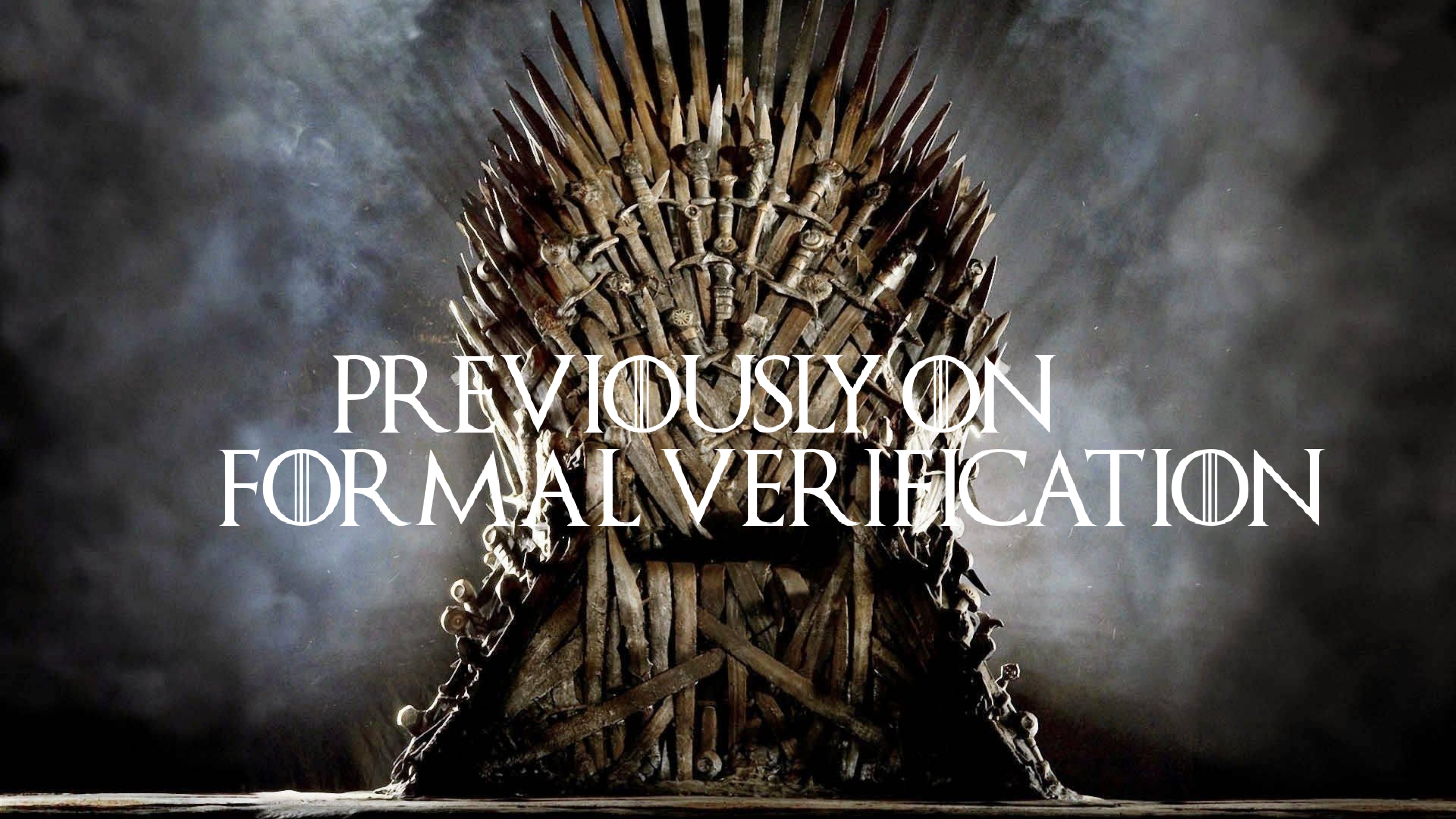
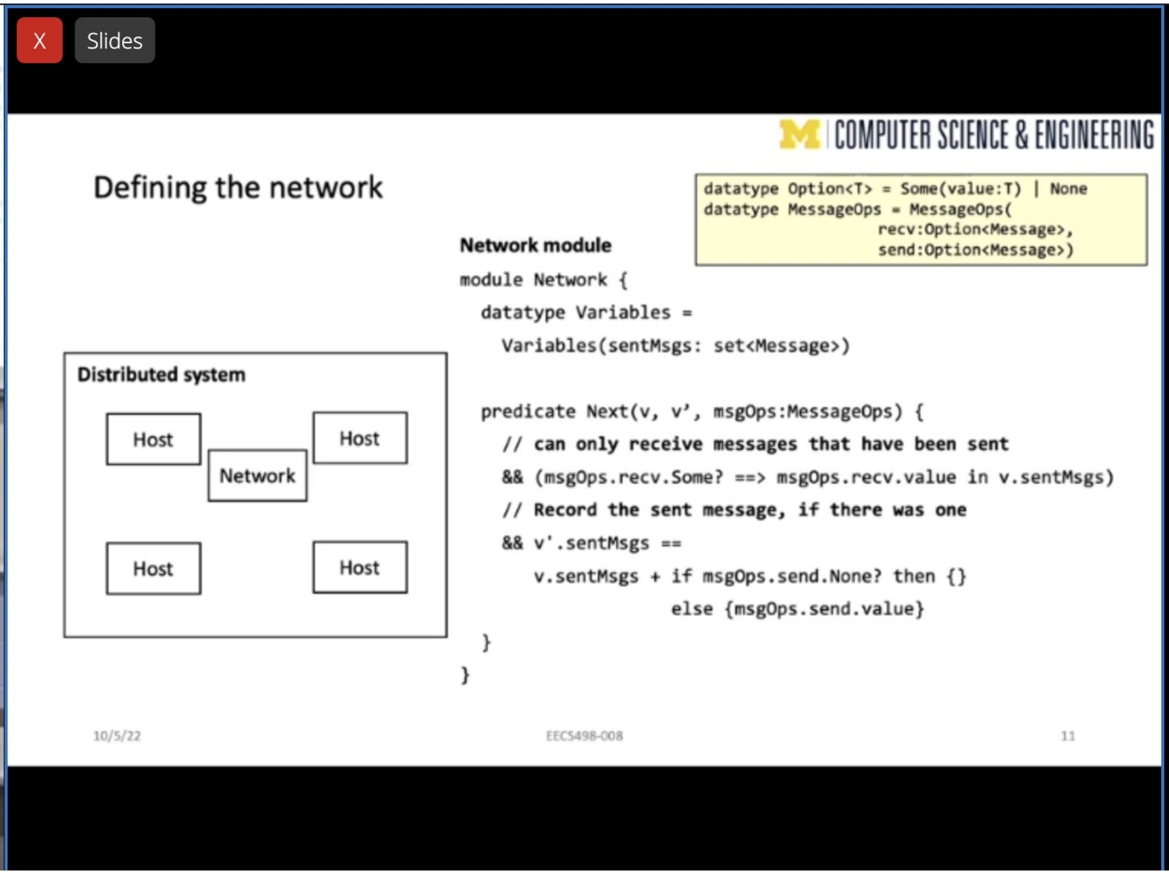


PREVIOUSLY ON FORMAL VERIFICATION



Defining the network

```
datatype Option<T> = Some(value:T) | None
datatype MessageOps = MessageOps(
                        recv:Option<Message>,
                        send:Option<Message>)
```

Network module

```
module Network {
  datatype Variables =
    Variables(sentMsgs: set<Message>)

  predicate Next(v, v', msgOps:MessageOps) {
    // can only receive messages that have been sent
    && (msgOps.recv.Some? ==> msgOps.recv.value in v.sentMsgs)
    // Record the sent message, if there was one
    && v'.sentMsgs ==
       v.sentMsgs + if msgOps.send.None? then {}
                    else {msgOps.send.value}
  }
}
```

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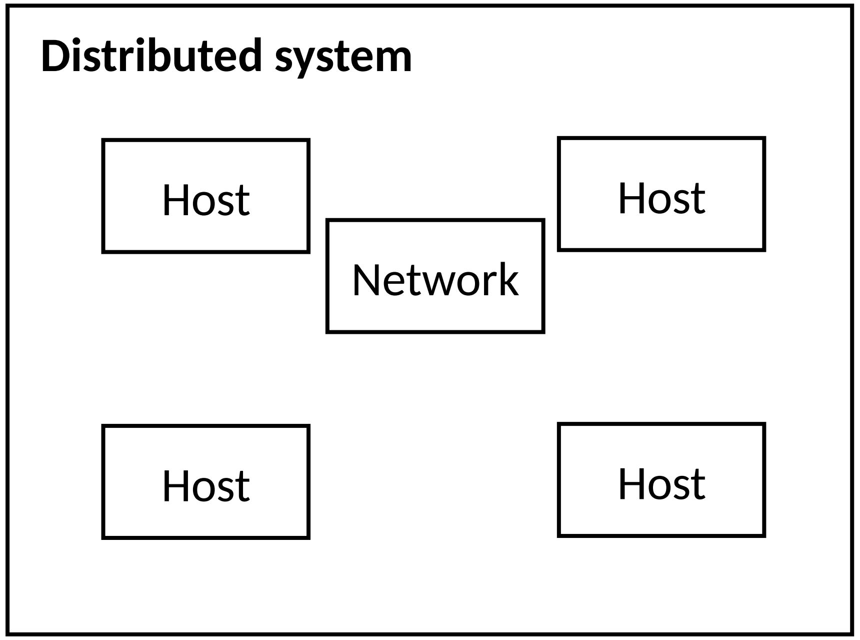
Defining the network

```
datatype Option<T> = Some(value:T) | None
datatype MessageOps = MessageOps(
                          recv:Option<Message>,
                          send:Option<Message>)
```

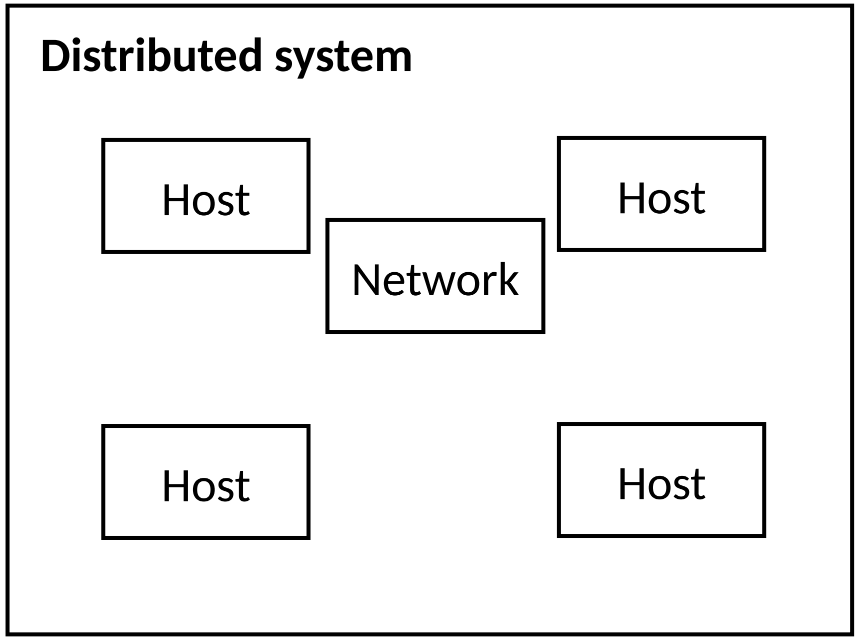


Network module

```
module Network {
  datatype Variables =
    Variables(sentMsgs: set<Message>)

  predicate Next(v, v’, msgOps:MessageOps) {
    // can only receive messages that have been sent
    && (msgOps.recv.Some? ==> msgOps.recv.value in
v.sentMsgs)
    // Record the sent message, if there was one
    && v'.sentMsgs ==
       v.sentMsgs + if msgOps.send.None? then {}
                    else {msgOps.send.value}
  }
}
```

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



Distributed system: attempt #2

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

  predicate HostAction(v, v’, hostid, msgOps) {
    && Host.Next(v.hosts[hostid],v'.hosts[hostid],msgOps))
    && forall otherHost:nat | otherHost != hostid ::
        v’.hosts[otherHost] == v.hosts[otherHost]
  }

  predicate Next(v, v’, hostid, msgOps: MessageOps) {
    && HostAction(v, v’, hostid, msgOps)
    && Network.Next(v, v’, msgOps)
  }
}
```

Binding variable

Administrivia

- Midterm exam **this Wednesday**, 10/12
  - 6-8pm, EECS1303
  - No lecture that day
- Closed books
  - Allowed one double-sided “cheat-sheet”, 10pt minimum
- Covers everything up to Chapter 4 (i.e. excluding distributed systems)

- Problem set 3 (Chapter 5) will be released later today
- Start looking for partners for Project 1 (released after PS3)

Atomic Commit (Problem Set 3)

-Do you take each other?
  -I do.
  -I do.
-I now pronounce you atomically committed.

Atomic Commit: the objective

Preserve data consistency for distributed transactions

Example: book a hotel and flight on Expedia

Atomic Commit: the setup

- One coordinator
- A set of participants
  - Allowed to be empty in our model
- Every participant has an “input” value, called vote/preference

$$vote_i \in \{Yes, No\}$$

- Every participant/coordinator has an “output” value, called decision

$$decision_i \in \{Commit, Abort\}$$

- We are ignoring the possibility of failures

Atomic Commit: the spec (simplified to ignore failures)

- AC-1: All processes that reach a decision reach the same one
- AC-3: The Commit decision can only be reached if all processes vote Yes
- AC-4: If ~~there are no failures and~~ all processes vote Yes, then the decision must be Commit

AC-2 and AC-5 ignored

Two Phase Commit (2PC)

Coordinator c

```
1. sends VOTE-REQ message to all participants
```

Participant p_i

```
2. sends $vote_i$ to coordinator
    if $vote_i$ == No
    then $decision_i$ := Abort
```

Coordinator c

```
3. Wait for all votes to come in
    If all votes are Yes then
        $decision_c$ := Commit
        Send Commit message to all
    else
        $decision_c$ := Abort
        Send Abort message to all who voted Yes
```

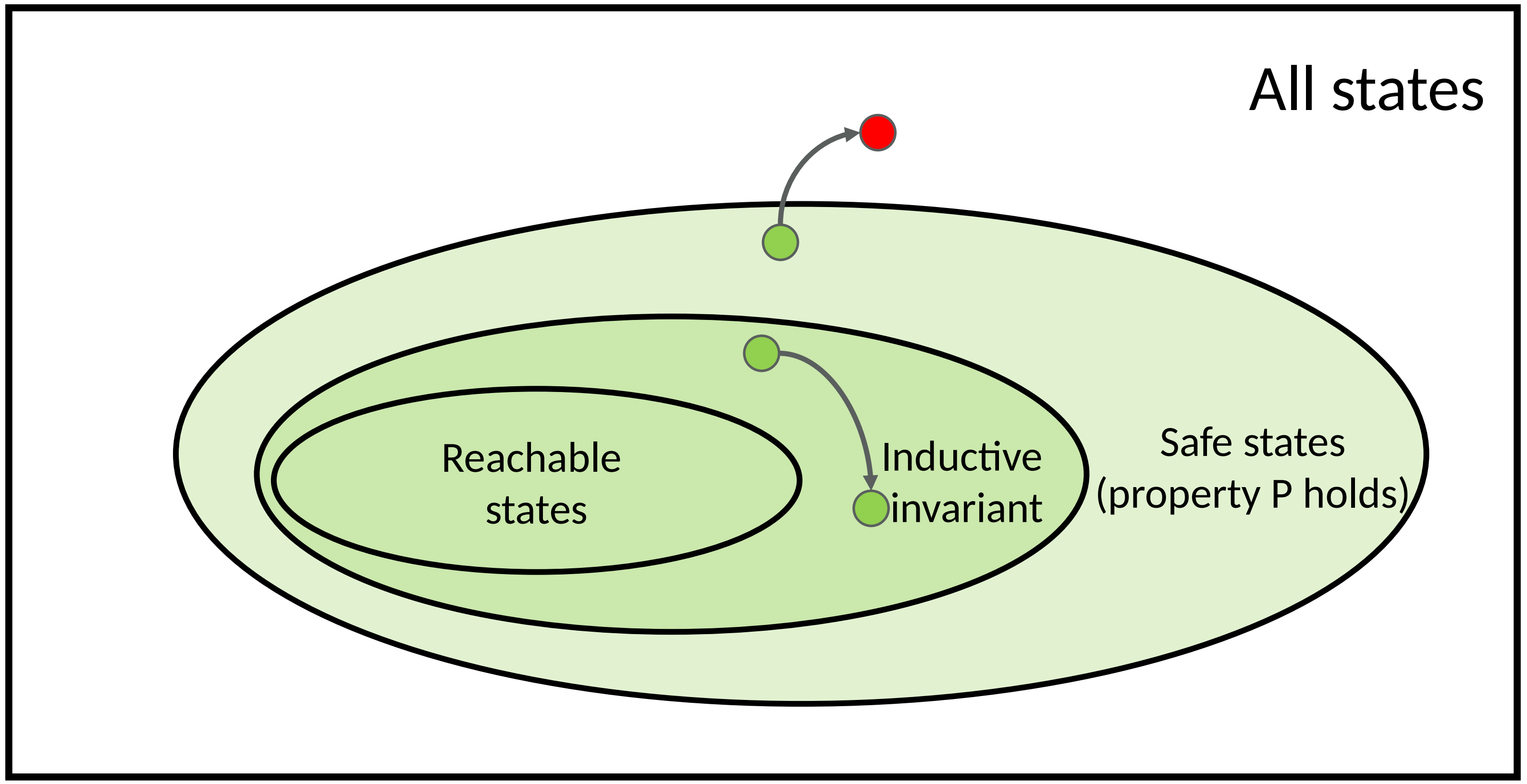
Participant p_i

```
4. If received Commit then
        $decision_i$ := Commit
    else
        $decision_i$ := Abort
```

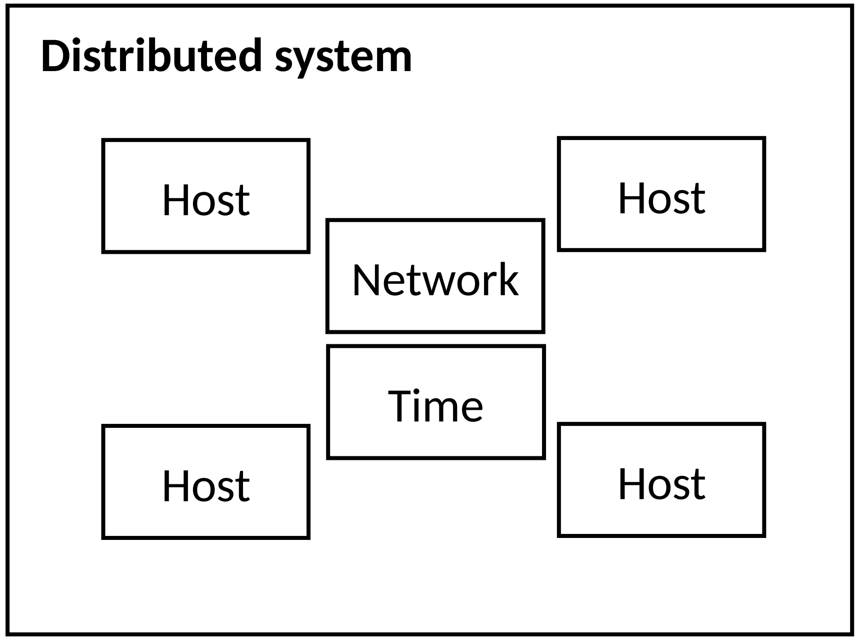
Recap of Chapters 1-4

- Chapter 1: Dafny mechanics
  - Primitive types, quantifiers, assertions, recursion, loop invariants, datatypes
- Chapter 2: Specification
  - Formally define how a system should behave
- Chapter 3: State machines
  - Express the behavior of a system using Init() and Next() predicates, JNF
- Chapter 4: Inductive invariants
  - A strengthening of the safety property to become inductive

Invariants vs Inductive invariants



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

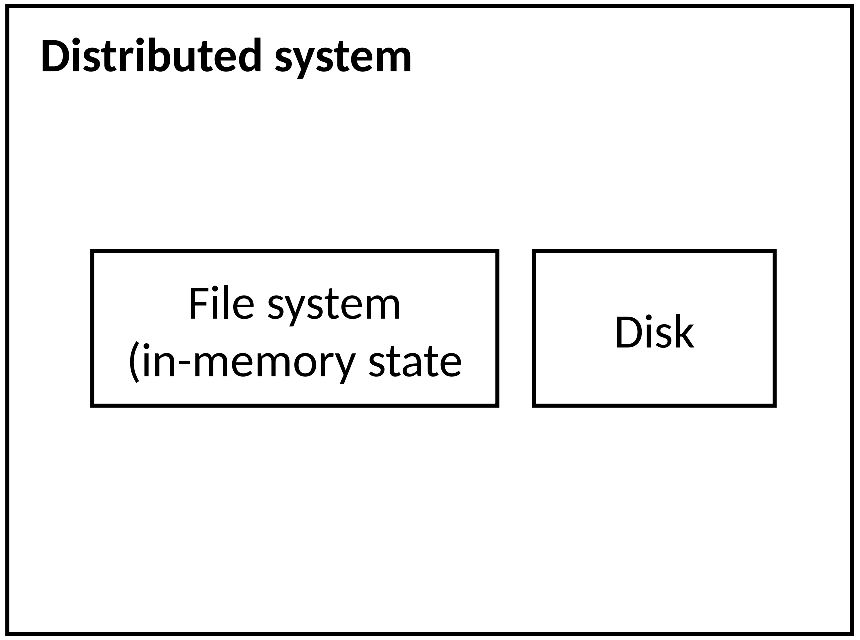


Distributed system: attempt #3

```
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

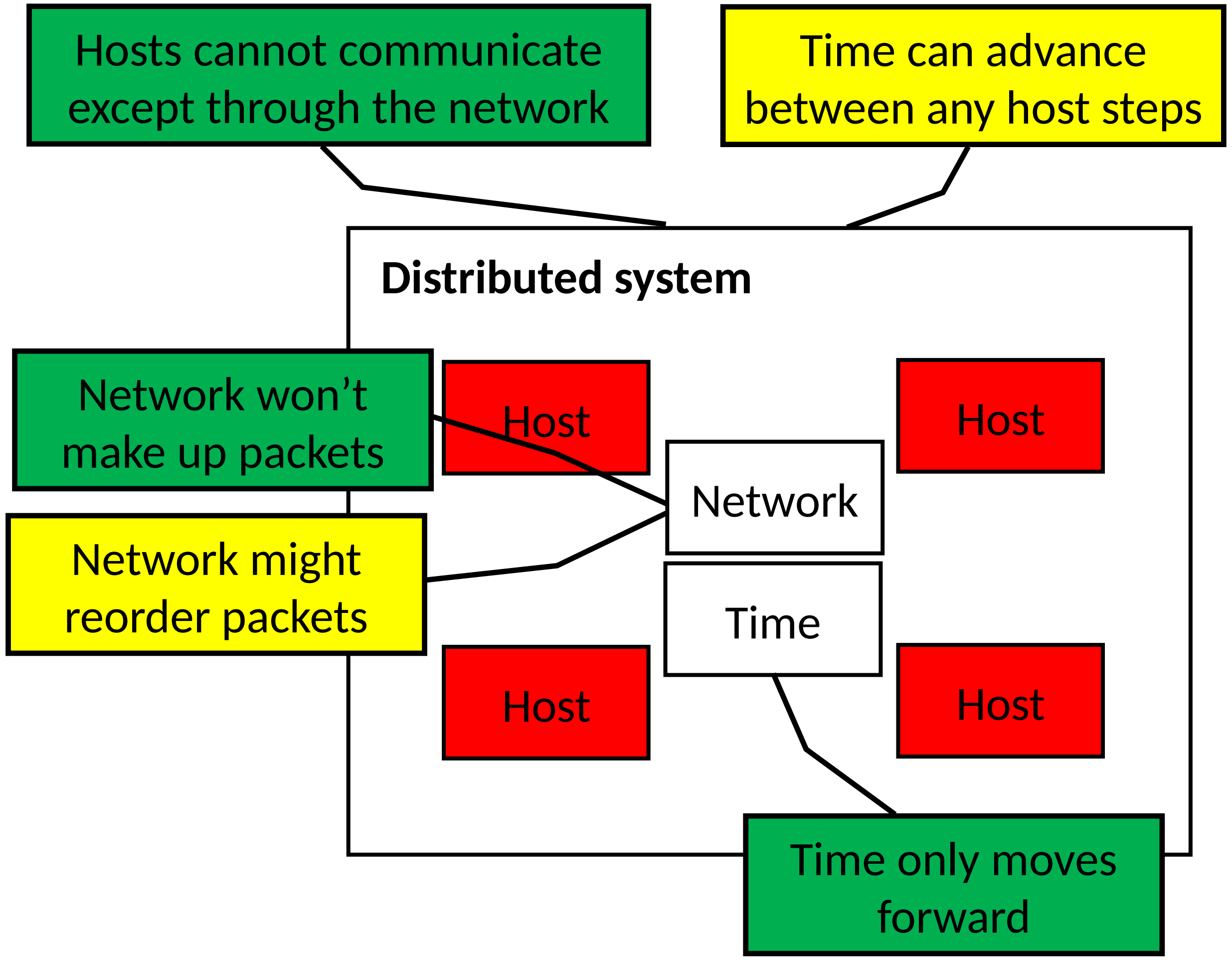


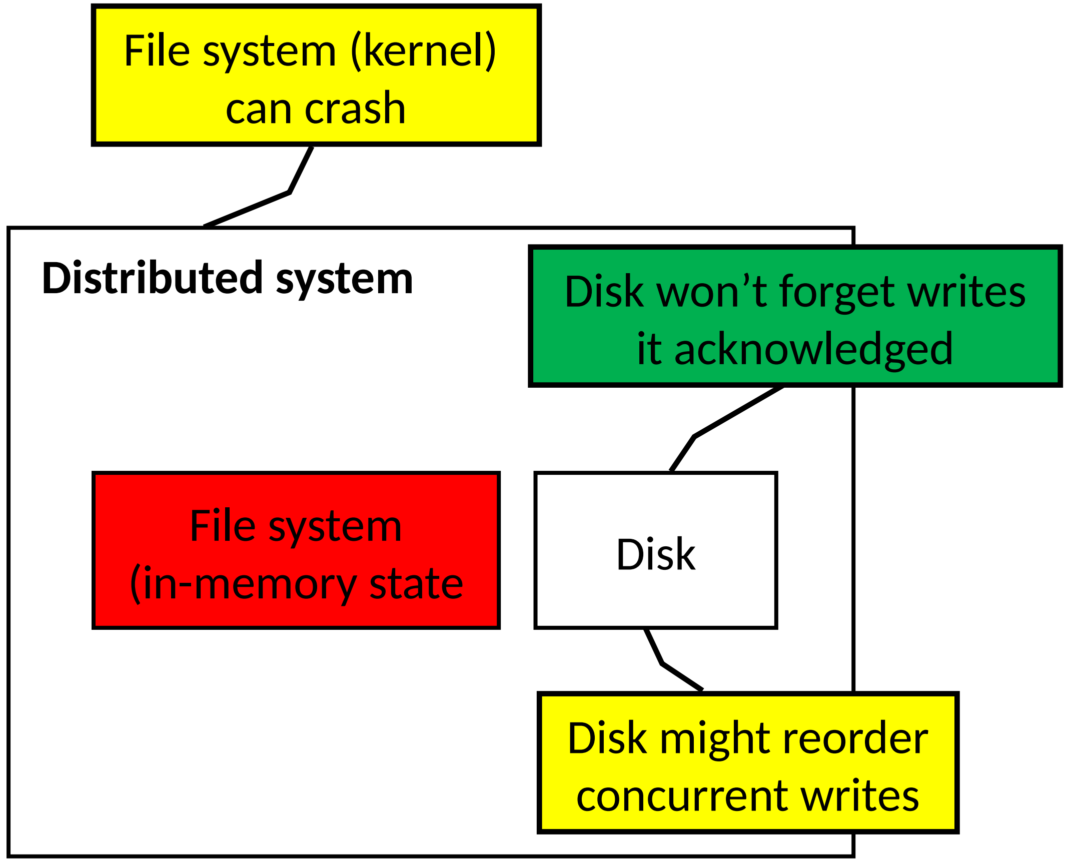
```
module DistributedSystem {
  datatype Variables =
    Variables(fs: FileSystem.Variables,
              disk: Disk.Variables)

  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

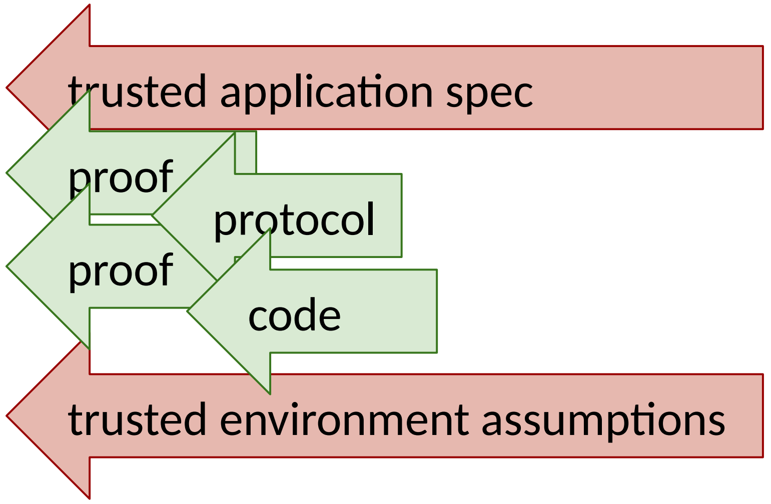
Trusted vs proven


Hosts cannot communicate except through the network
Time can advance between any host steps
Distributed system
Network won't make up packets
Network might reorder packets
Host
Host
Network
Time
Host
Host
Time only moves forward


File system (kernel) can crash
Distributed system
Disk won't forget writes it acknowledged
File system (in-memory state
Disk
Disk might reorder concurrent writes

SPECIFICATION: the systems specification sandwich

image: pixabay


trusted application spec
proof
protocol
proof
code
trusted environment assumptions