NETWORK CONFIGURATION IS HARD!

Georgia Tech

- High-level tasks are realized through low-level commands and scripts: **hard to understand**
- Distributed configuration: **hard to manage**
- Variety of network-wide tasks cause changes to the network: **lots of dynamics**
- No changes are checked for correctness:

  error-prone

SURVEY WITH NETWORK OPERATORS

Georgia Tech

20% make changes more than once a day

89% are ***never*** completely certain that changes will not introduce a new bug

82% are concerned changes might break existing functionality unrelated to the changes

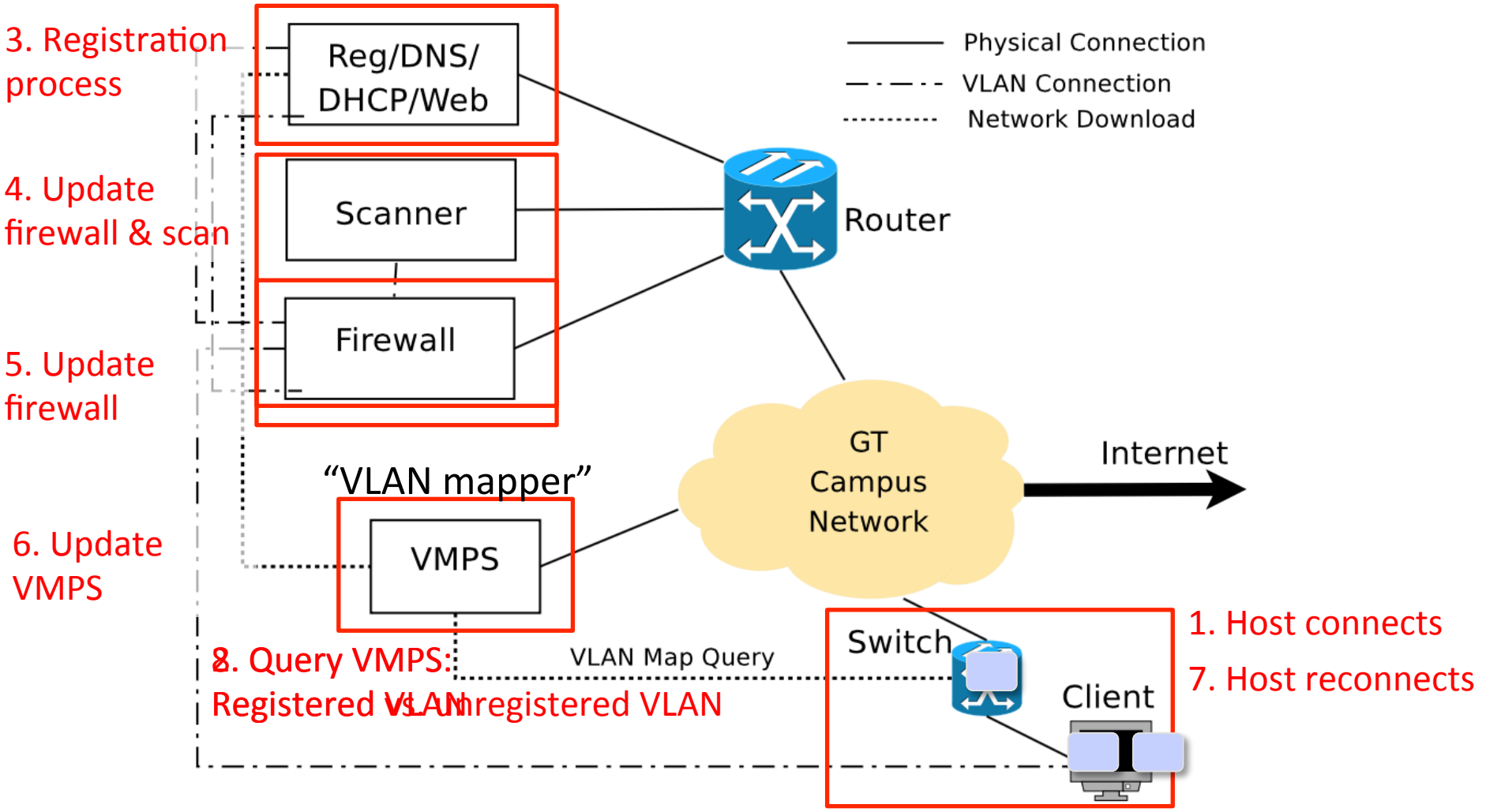
SURVEY WITH NETWORK OPERATORS

20% make changes more than once a day

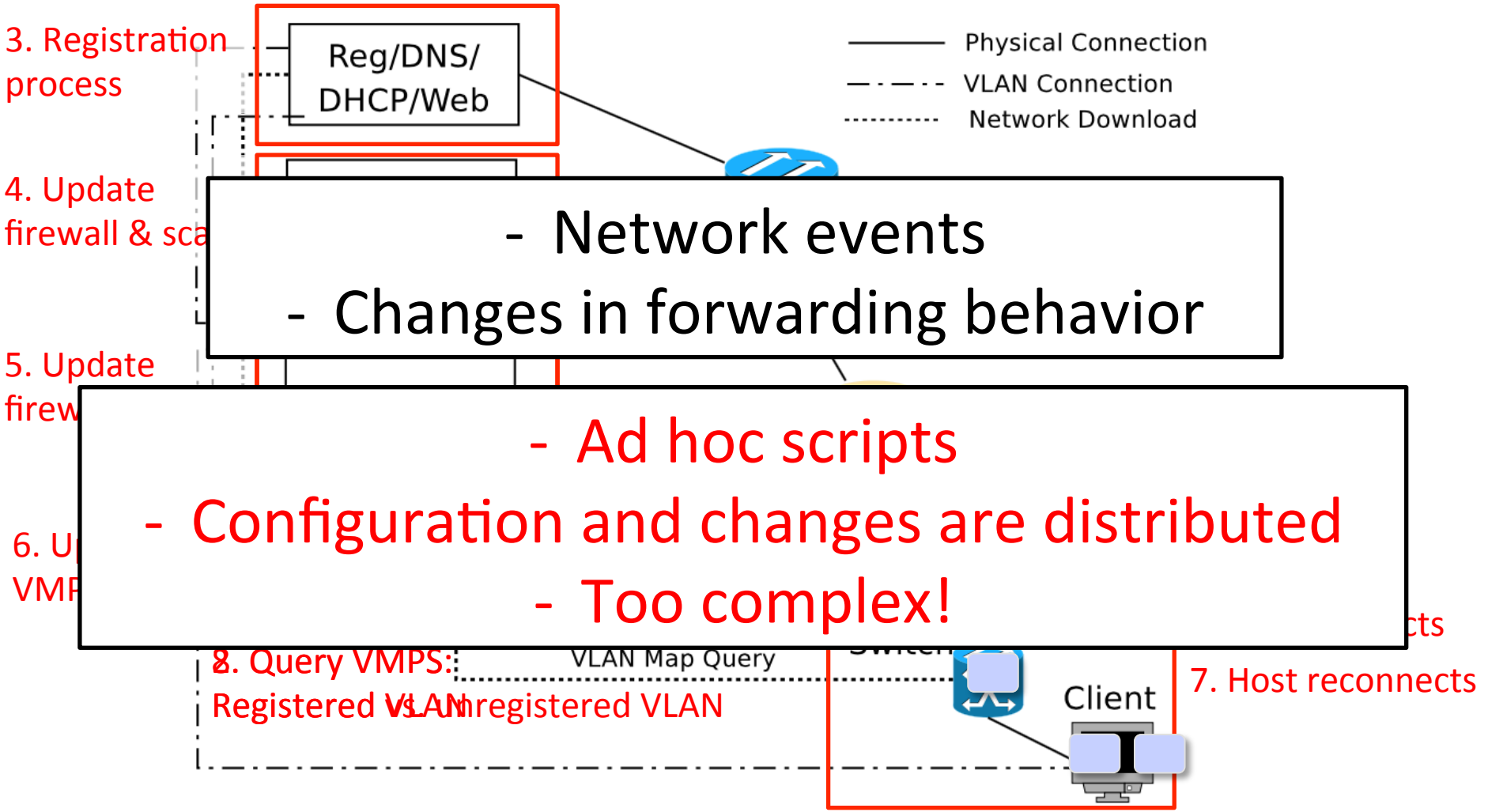
89% are ***never*** completely certain that changes will not introduce a new bug

"You should track down those 10-20% of operators who say they are always certain. They are LYING."

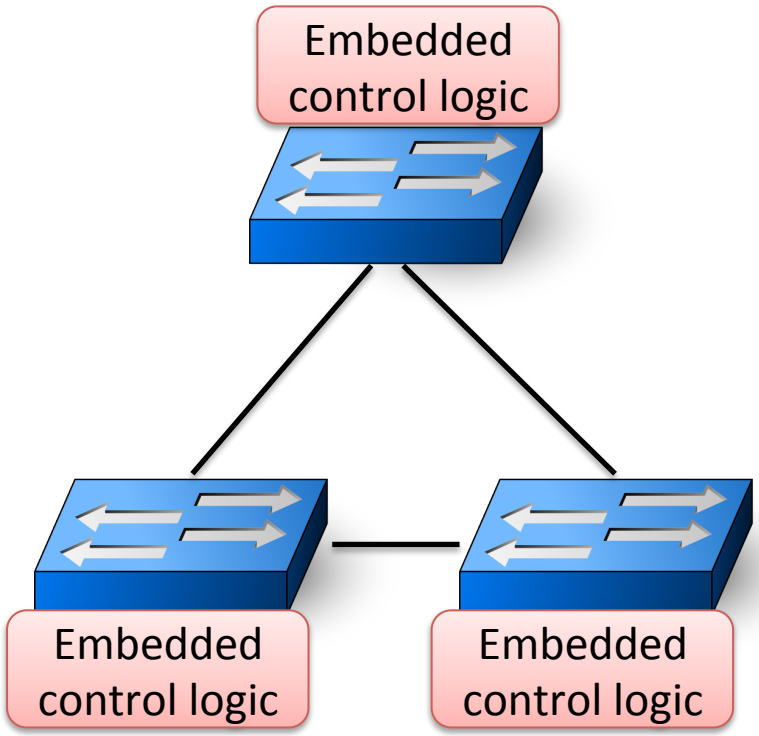
MOTIVATING EXAMPLE: THE *START* SYSTEM



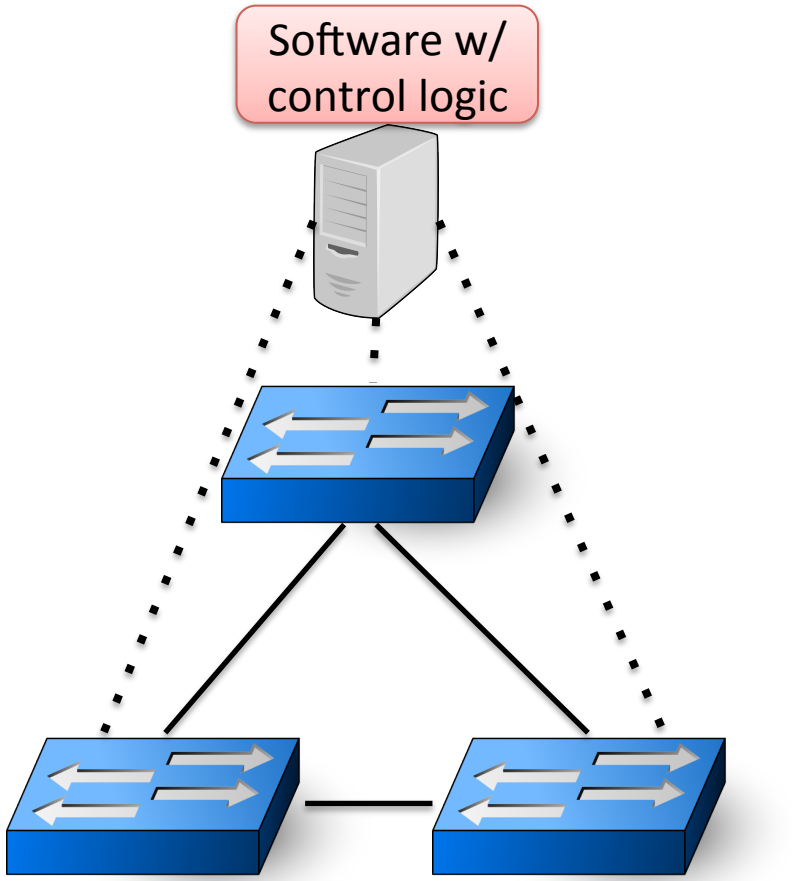
MOTIVATING EXAMPLE: THE *START* SYSTEM



SOFTWARE-DEFINED NETWORKING



Traditional network



SDN

SDN IS NOT A SILVER BULLET

Georgia Tech

- Low-level commands & scripts: **hard to understand**

  Programs: e.g., C++, Java, Python, Pyretic

- Distributed configuration: **hard to manage**

  Central control

- Many network-wide tasks, lots of changes: **lots of dynamics**

  Unsolved

- No correctness guarantee: **error-prone**

  Unsolved

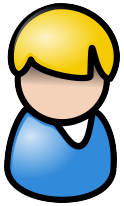
WHAT SDN PLATFORM NEEDS

- Guidance on how to implement a network control program
  - How to provide ***dynamic control*** that handles arbitrary network events
  - E.g, Intrusion detection, traffic load shift, etc
- Verification and guarantees of program's correctness
- Huge missed opportunities in software

DIFFERENT TYPES OF NETWORK EVENTS

- Network traffic
  - Traffic load increase/decrease, security incidents
- User-specific
  - User authentication, excessive data usage
- Data-plane events
  - Topology change, switch/link failures
- …

DIFFERENT REACTIONS TO AN EVENT

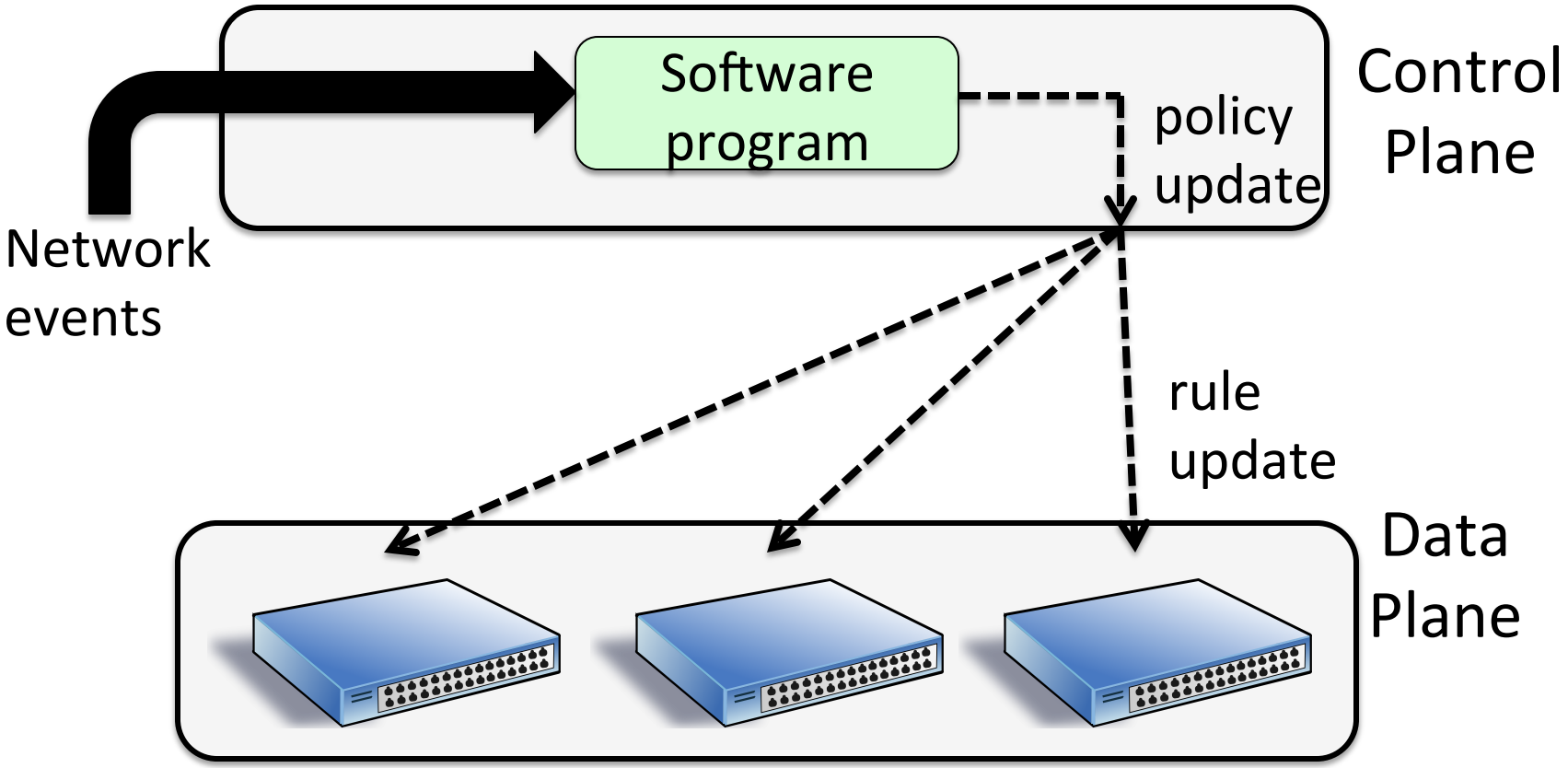
Event	Operators	Reaction
Host is infected!		"Only block that infected host"
		"Block all communications in the network!"
		"Direct communication to our internal honeypot"

INSIGHT

Network events and **dynamic reactions** to them should be **programmatically encoded** in the **network control program** by operators

DYNAMIC NETWORK CONTROL PROGRAM

- **Software program** that embeds event – reaction relationships



UNANSWERED QUESTIONS

Georgia Tech

How to **embed event-reaction logic** in software?

How to **verify** that the program will make **changes correctly**?

Kinetic tackles these questions

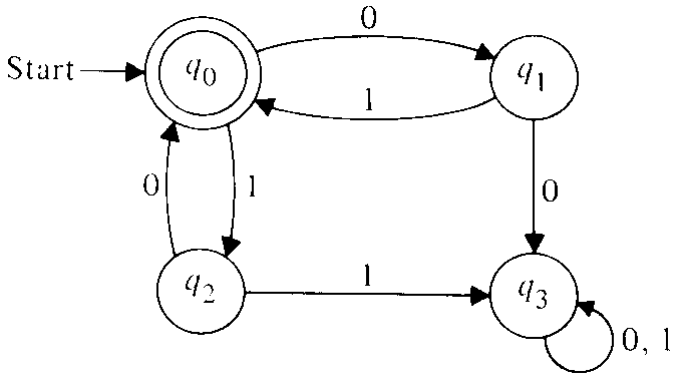
KINETIC

- **Domain specific** language and control platform
- Helps create SDN control programs that **embed custom event-reaction** relationships
- **Verifies** program's **correctness**

OUR APPROACH

- Domain specific language
  - Constrained, but structured

- Express changing behavior as a ***finite state machine***

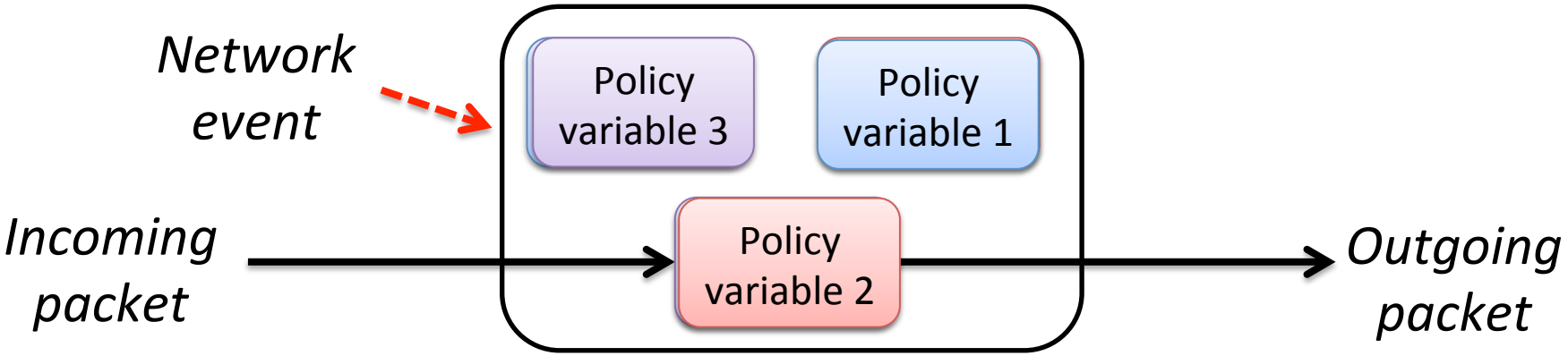


- Verify program's correctness with a model checker (NuSMV)

KINETIC'S DOMAIN SPECIFIC LANGUAGE

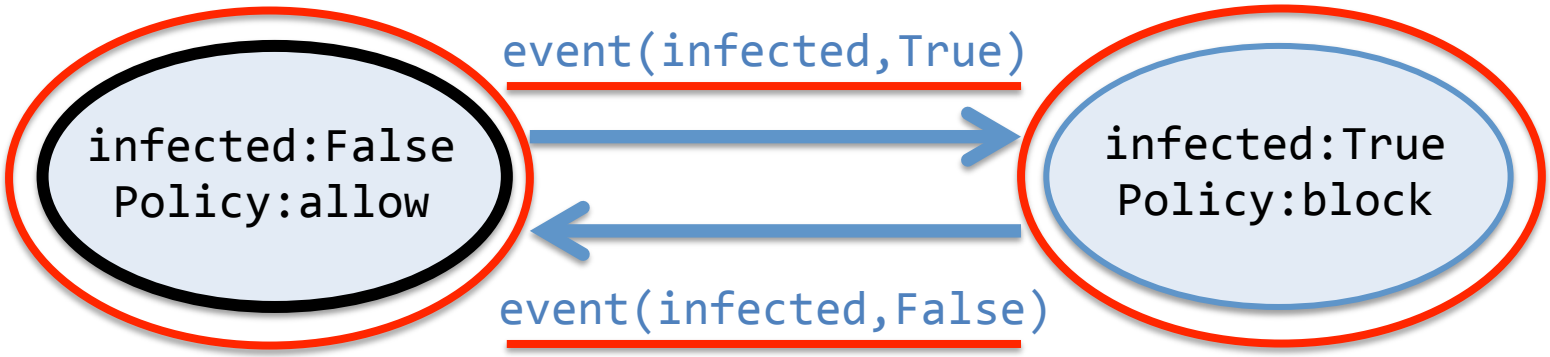
- Embedded in Python
- Borrows some abstractions from Pyretic
  - Encodes forwarding behavior in a *policy variable*

- New constructs and functions to express policies that respond to *changing conditions*



IDS EXAMPLE IN KINETIC

- **Event**: *infected*
- **State**: policy variable's value
  - *allow* or *block* packet

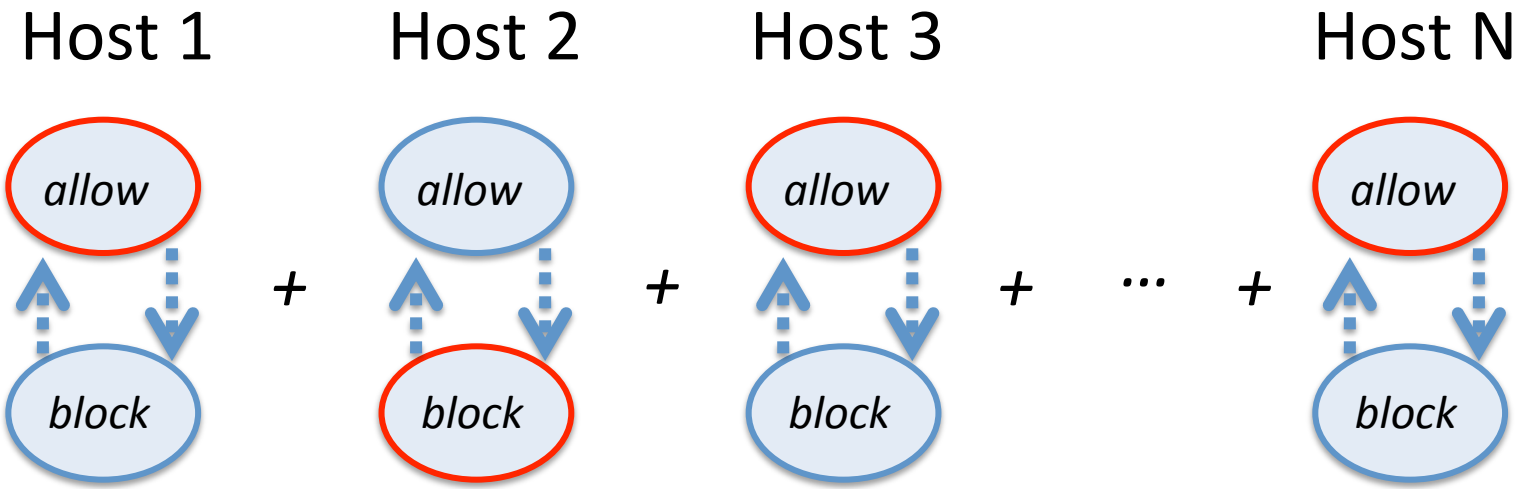


There are many different flows

Each flow can have its own independent FSM

DECOMPOSING TO MULTIPLE FSMS

- FSM instance is instantiated per flow



# of hosts: N *Total # of states: 2N* *Total # of transitions: 2N*

State representation is ***Linear*** in N
(instead of geometric)

LPEC: ABSTRACTION TO DEFINE A FLOW

Georgia Tech

- In IDS example, flow is defined by source IP address (host)
- Other policies may require more flexibility (e.g., need to group packets by location)
- **Located Packet Equivalence Class (LPEC)**
  - Programmer abstraction to define *flow*

```
def lpec(pkt):
    return match(dstip=pkt['dstip'])
```

KINETIC VERIFICATION PROCESS

Georgia Tech

- Kinetic verifies correctness of the program
  - User-specified temporal properties
  - Verifies ***current and future*** forwarding behavior based on network events
- Verification process is ***automated***
  - Constrained but structured language allows automatic parsing and translation of program
- Verification runs ***before program's deployment***

VERIFICATION PROCESS

Kinetic program

```
@transition
def infected(self):
  self.case(occured(self.event),self.event)

@transition
def policy(self):
  self.case(is_true(V('infected')),C(drop))
  self.default(C(identity))

self.fsm_def = FSMDef(
  infected=FSMVar(type=BoolType(),
                  init=False,
                  trans=infected),
  policy=FSMVar(type=Type(Policy,{drop,
      identity}),
                init=identity,
                trans=policy))
```

Automatically generates

NuSMV FSM model

```
MODULE main
  VAR
    policy   : {identity,drop};
    infected : boolean;
  ASSIGN
    init(policy)   := identity;
    init(infected) := FALSE;
  next(policy) :=
    case
      infected : drop;
      TRUE     : identity;
    esac;
  next(infected) :=
    case
      TRUE     : {FALSE,TRUE};
  esac;
```

User-specified temporal properties

NuSMV Model Checker

True or False

(w/ counter-example)

EXAMPLES OF TEMPORAL PROPERTIES

- If a host is infected, drop packets from that host

AG (infected → AX policy=drop)

For all possible transitions from current state,

For all current and future states,

For all possible transitions from current state,

For the next state,

- If host is authenticated either by Web or 802.1X, and is not infected, packets should never be dropped.

AG ((authenticated_web | authenticated_1x) & !infected → AX policy!=drop)

EVALUATION

- Usability evaluation
  - User study against over 870 participants
  - Lines of code comparison with other SDN solutions
- Performance and scalability
  - Event handling and policy recompilation

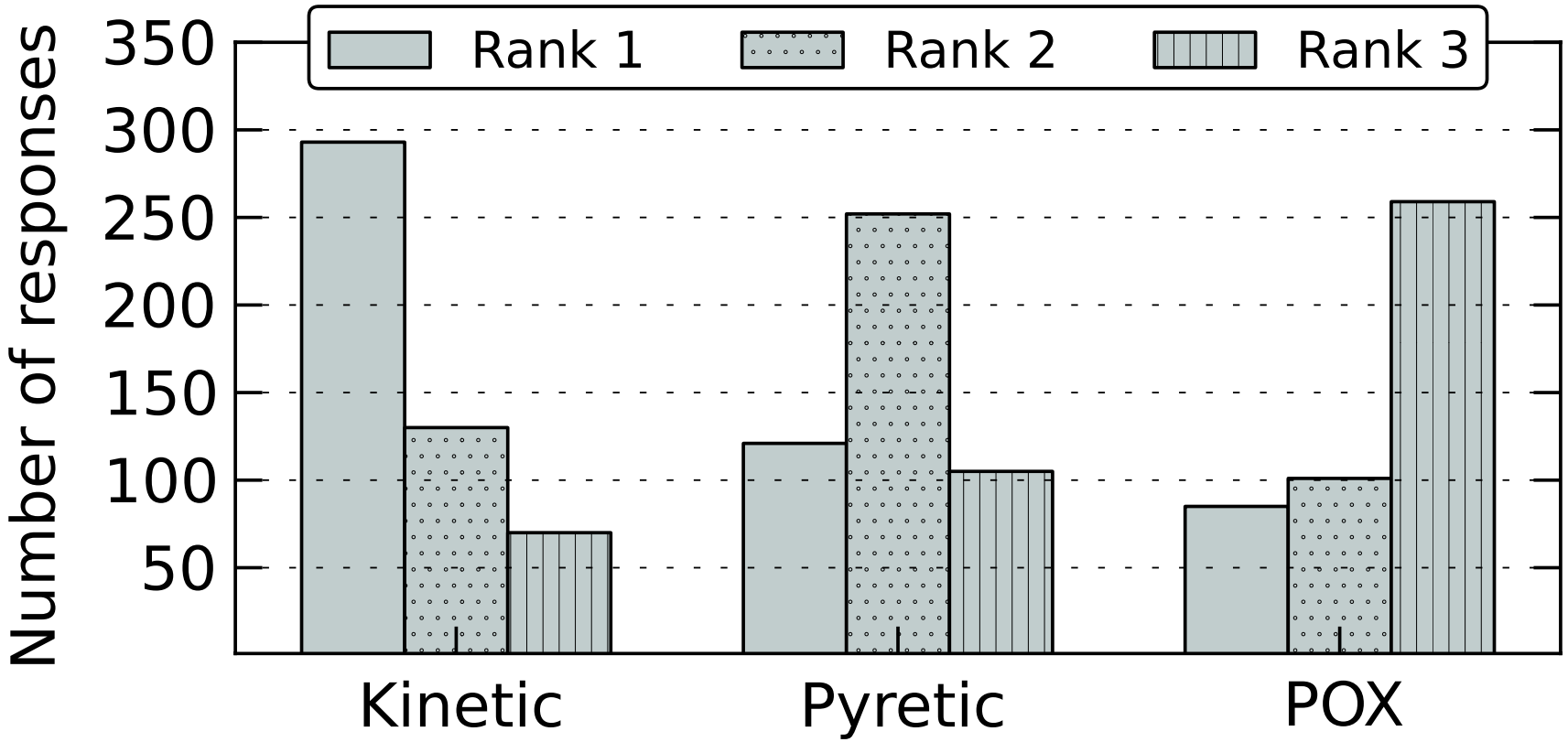
KINETIC: USER STUDY

- Demographic

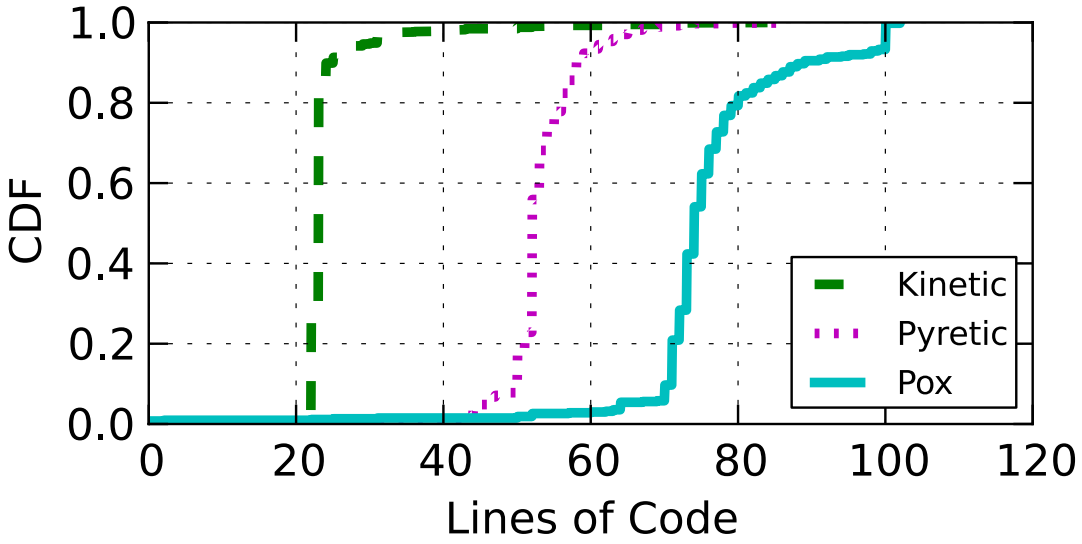
Profession		Experience (years)	
Operator	216	1	32
Developer	251	1-5	310
Student	123	5-10	187
Vendor	80	10-15	150
Manager	69	15-20	122
Other	138	> 20	73
Total	877		874

- Task
  - Implement an enhanced IDS program with Kinetic, Pyretic, and POX.

RANK PLATFORMS BY PREFERENCE



LINES OF CODE COMPARISON



Programs	FL	POX	Pyretic	Kinetic
IDS/firewall	416	22	46	17
Mac learner	314	73	17	33
Server load balance	951	145	34	37
Stateful firewall	*None found*	*None found*	25	41
Usage-based rate limiter	*None found*	*None found*	*None found*	30

NOTABLE QUOTES

- Why did you like Kinetic?
  - **FSM-based structure and support for intuition**

"Kinetic is more intuitive: the only things I need to do is to define the FSM variable"

"intuitive and easy to understand"

"Programming state transitions in FSMs makes much more sense"

  - **More concise**

"reduces the number of lines of code"

"the logic is more concise"

NOTABLE QUOTES

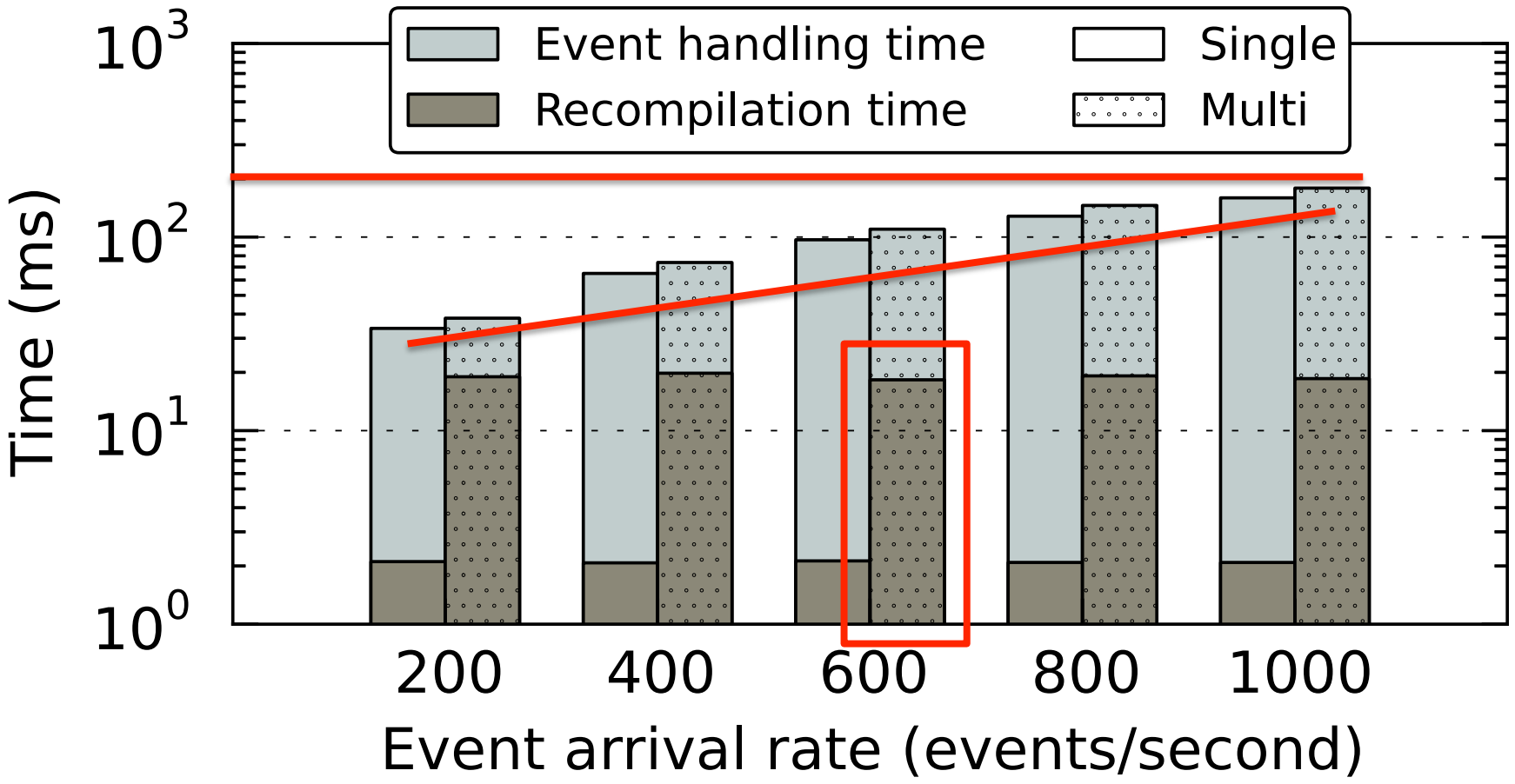
- Why ***didn't*** you like Kinetic?
  - **Steep learning curve**

    "Kinetic took less time and was actually more understandable …[but] the structure was very cryptic"

  - **Not friendly when finding why program is wrong**

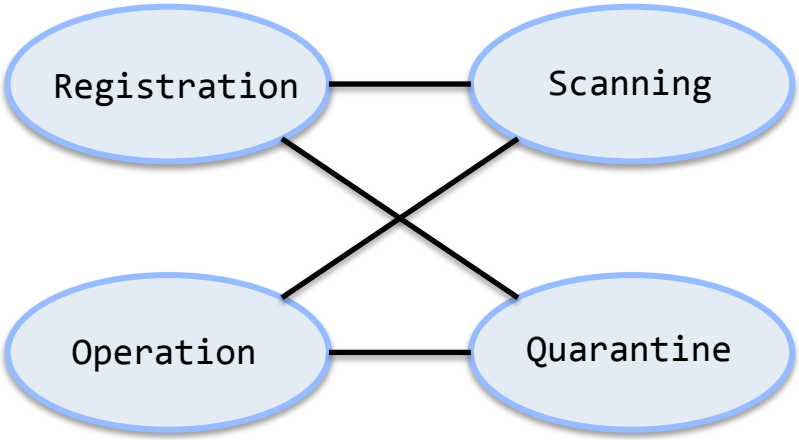
    "I spent a lot more time chasing down weird bugs I had because of things I left out or perhaps didn't understand"

Event handling and policy recompilation

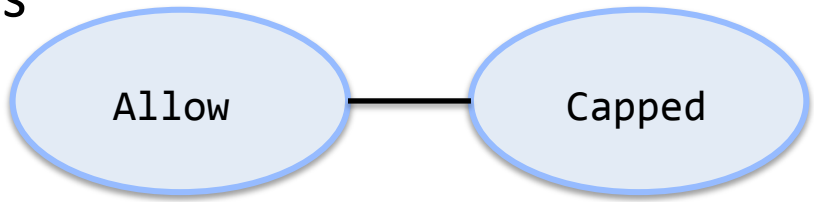


KINETIC: REAL DEPLOYMENTS

- Campus network
  - Functional access control system
  - Deployed SDN-enabled switches over 3 buildings



- Home network
  - Usage-based access control
  - Deployed 21 SDN-enabled wireless routers over 3 continents
  - Jul., 2012 – Feb., 2014
  - Presented in ACM CHI 2015



KINETIC TAKEAWAYS

- **Domain specific** language and control platform
  - Program **encodes event-reaction logic**
- **Extensive user study** shows that
  - Much **easier to express dynamics** in the network
  - Helps to **reduce lines of code**
- **Scales well** to large networks and lots of events
- **Verification process reduces bugs** in programs

DISCUSSION & FUTURE WORK

- Combining with verifications in other stacks
  - Consistent updates to data plane
  - Verification of data-plane state
- More dynamic network policies
  - Should collect more real network policies
  - Need public repository

THANK YOU

More about Kinetic:

http://kinetic.noise.gatech.edu

Contact:

joonk@gatech.edu

Questions?