NetCheck: Network Diagnoses from Blackbox Traces

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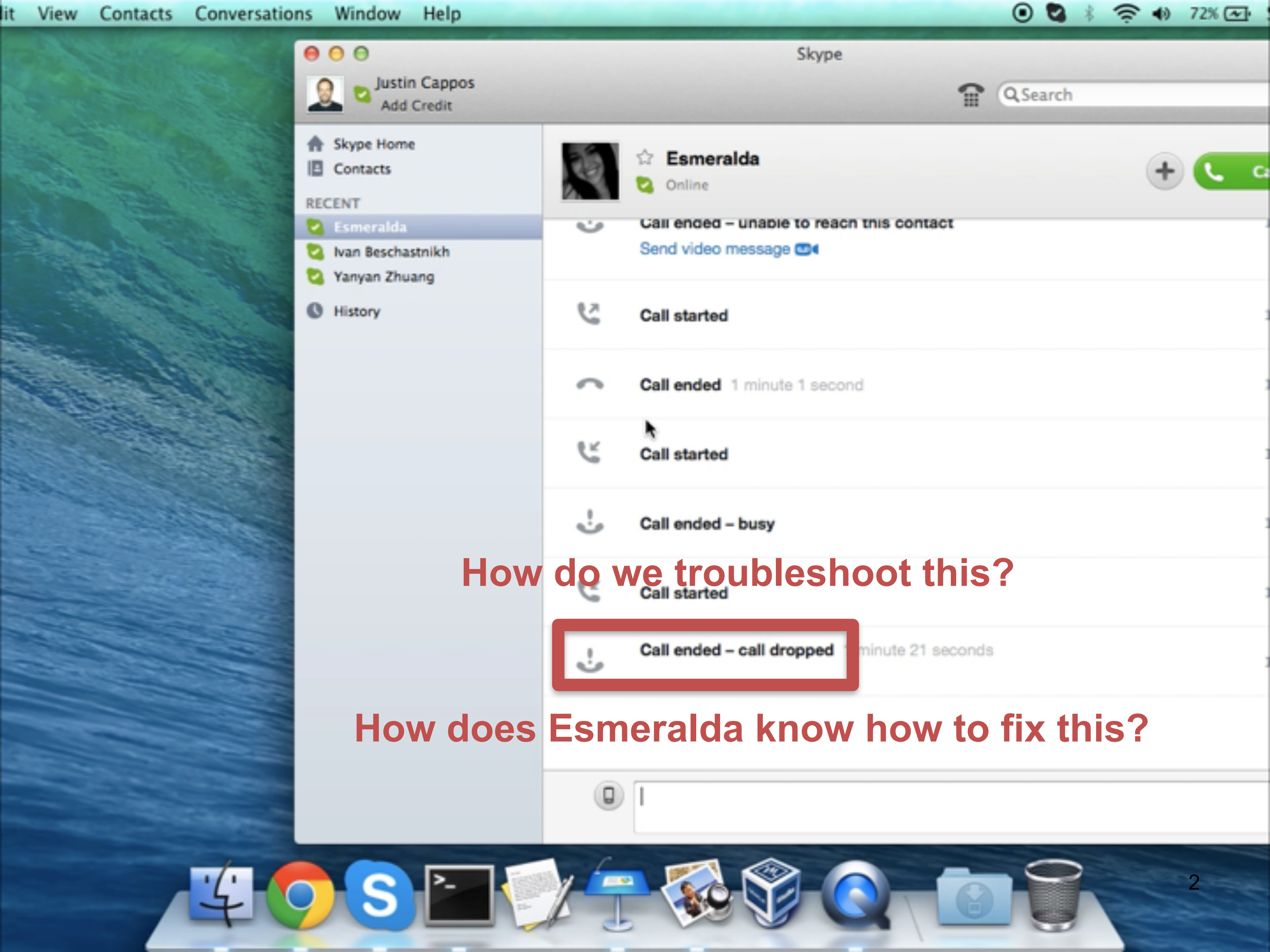


How do we troubleshoot this?

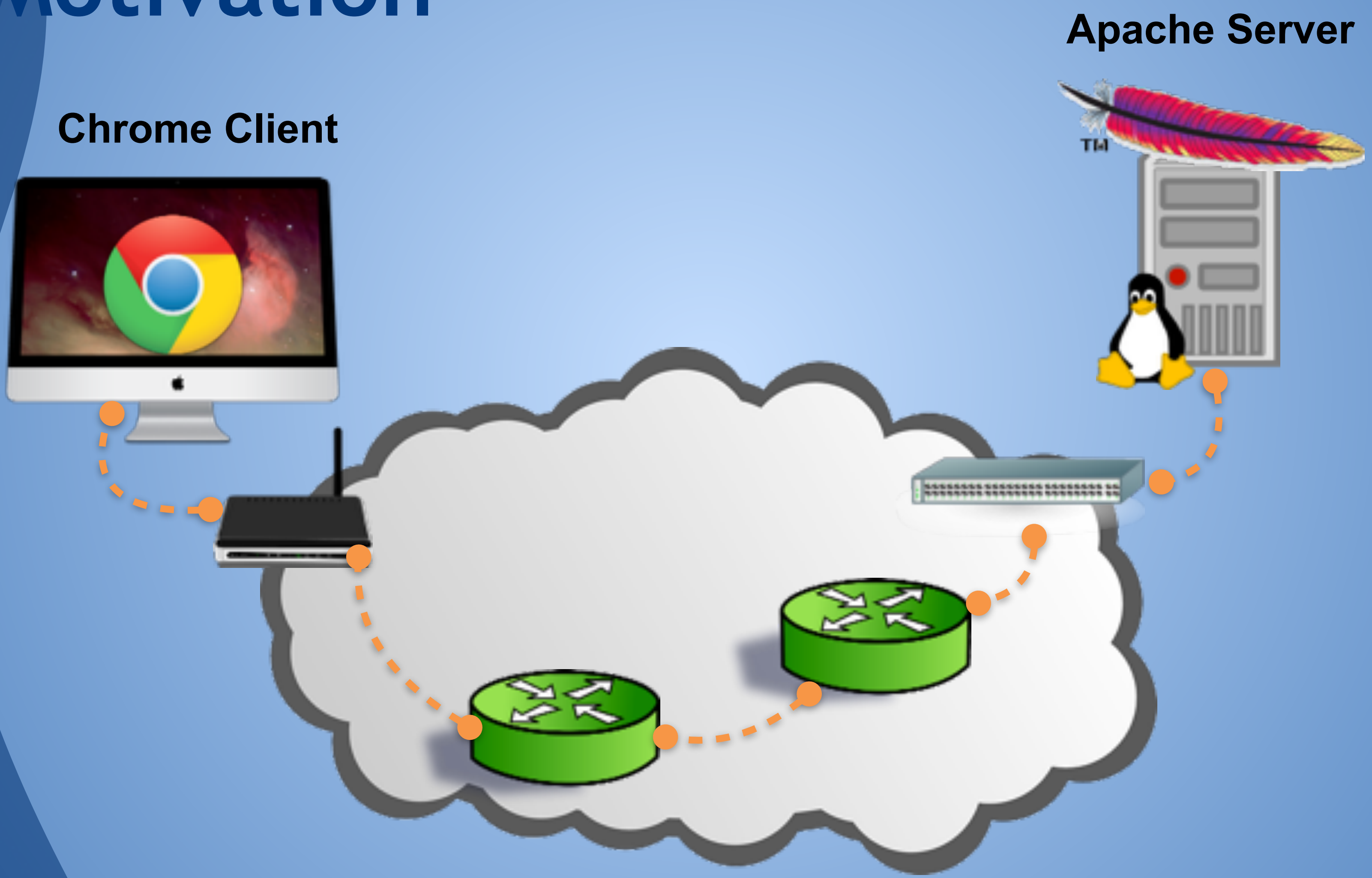
How does Esmeralda know how to fix this?

Goal

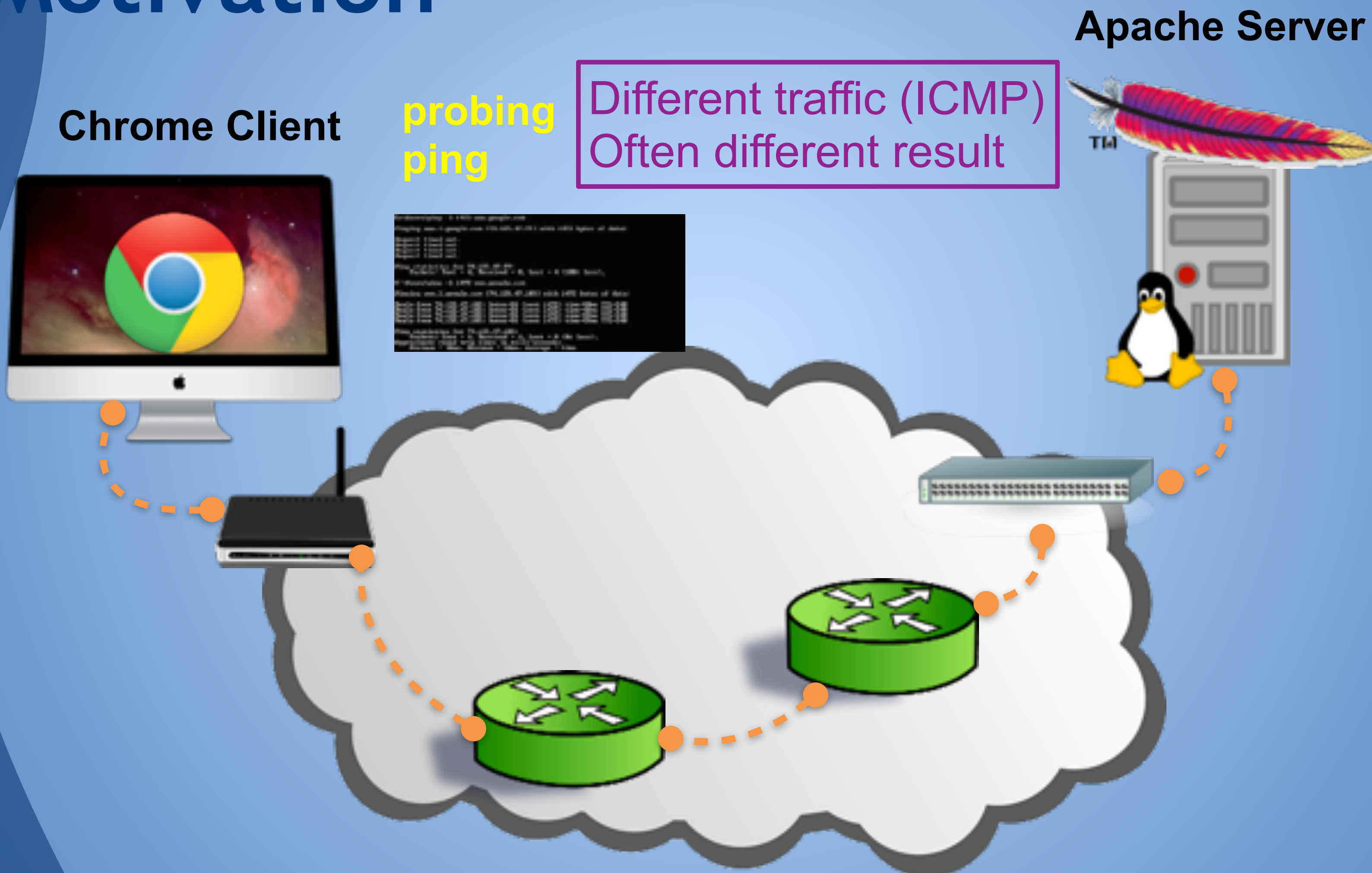
- Find bugs in networked applications
  - Large complex unknown applications
  - Large complex unknown networks

- Understandable output / fix

Motivation

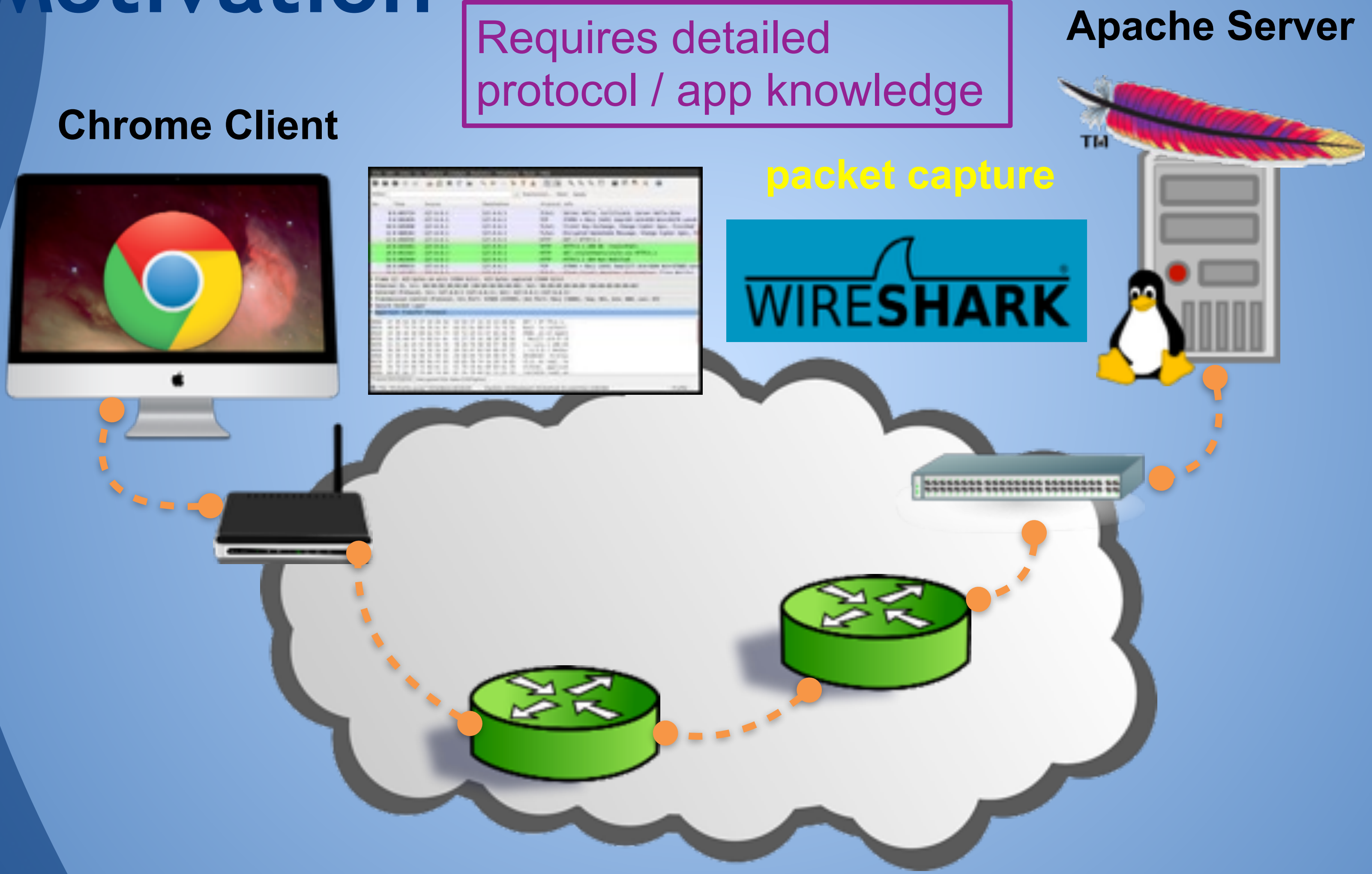


Motivation


Apache Server
Chrome Client
probing
ping
Different traffic (ICMP)
Often different result

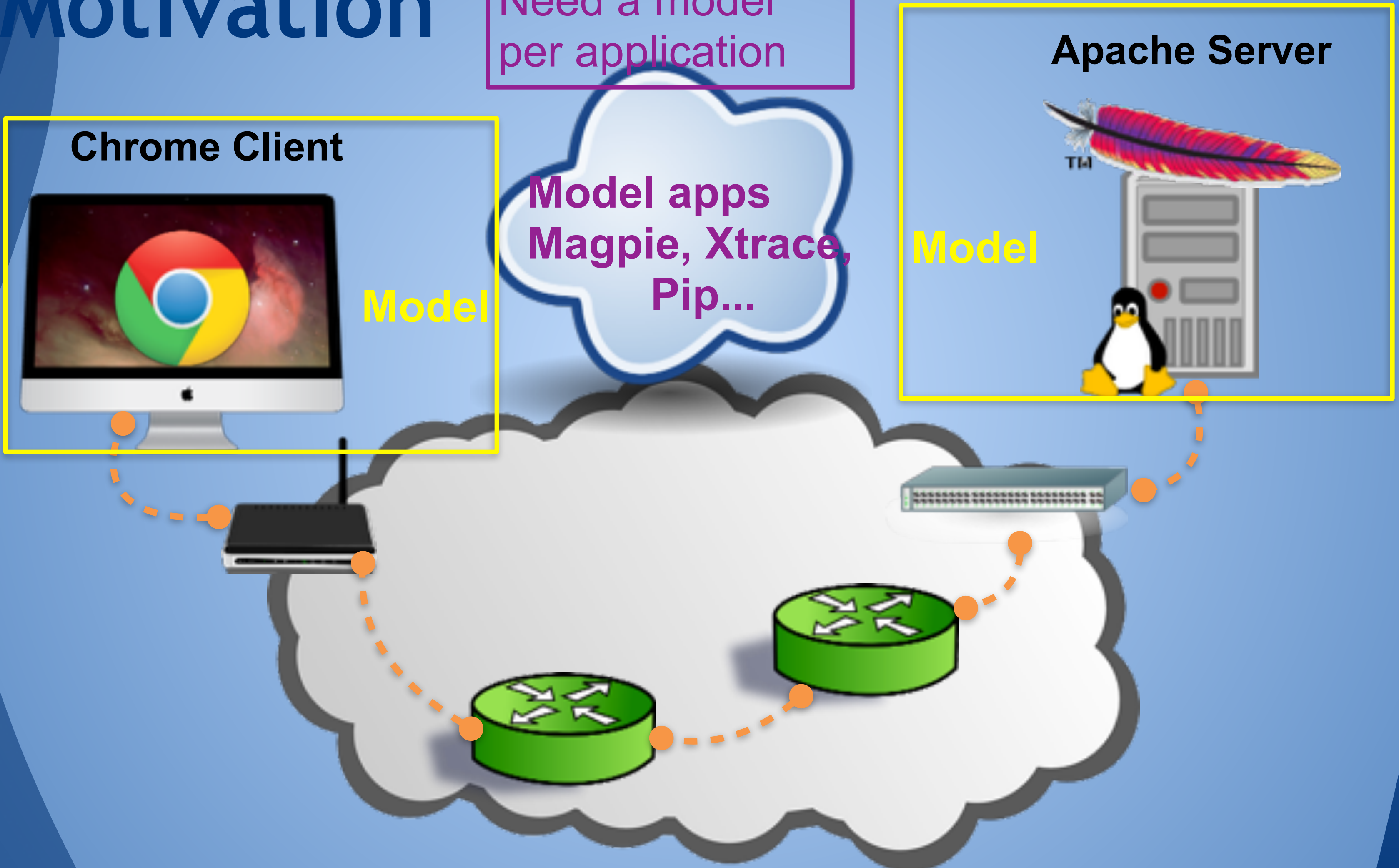
Motivation

Requires detailed
protocol / app knowledge

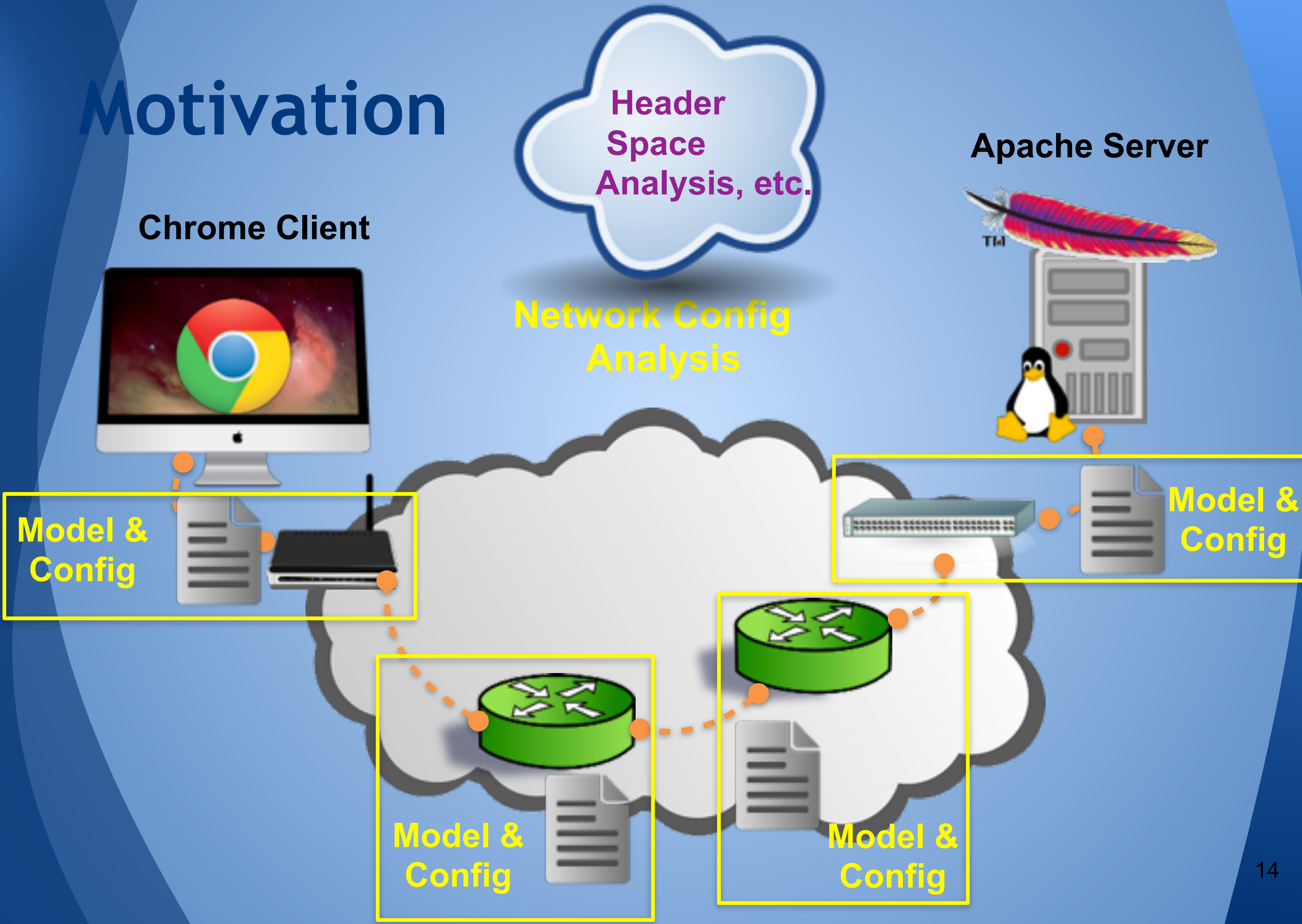


Motivation

Need a model per application



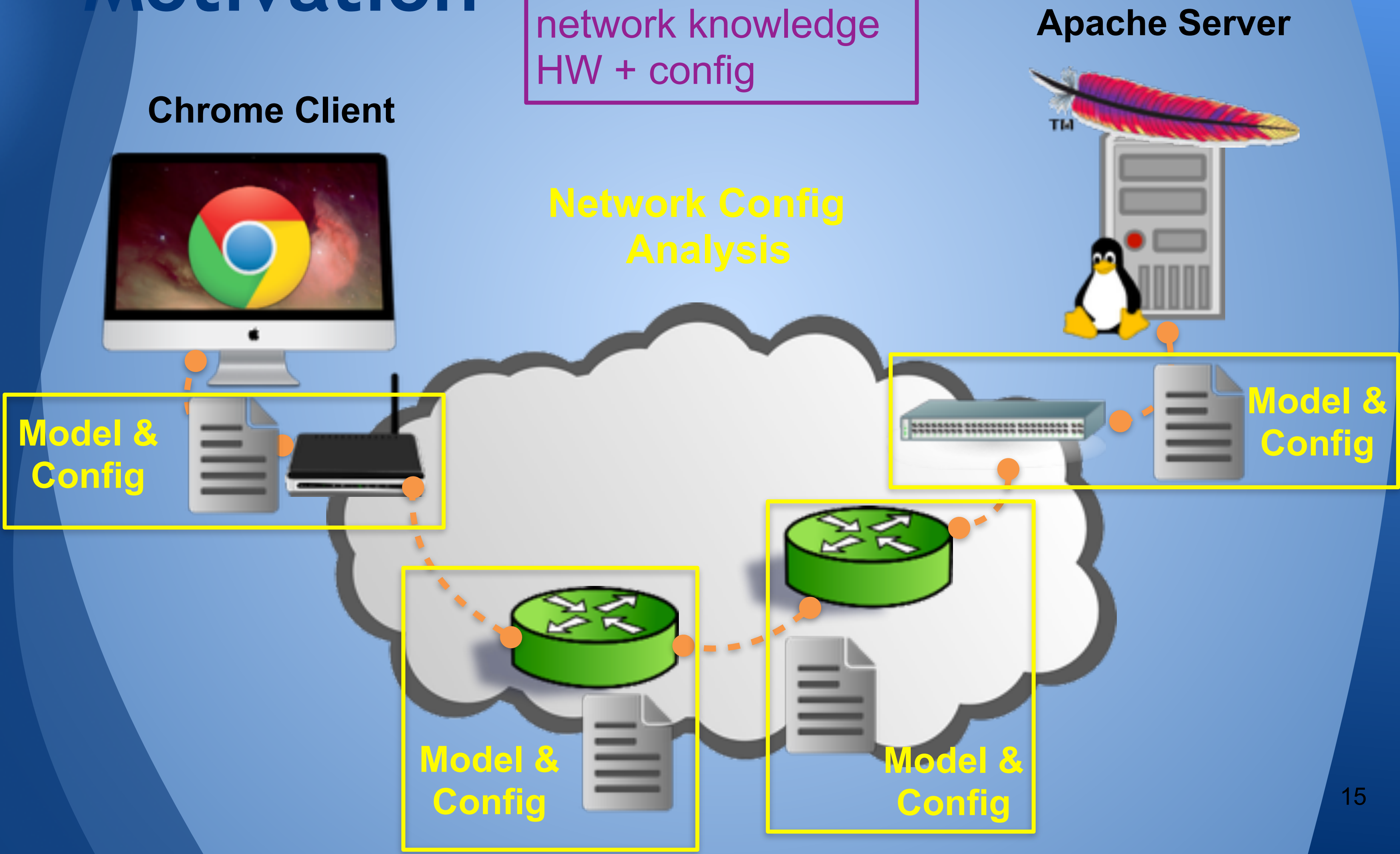
Motivation



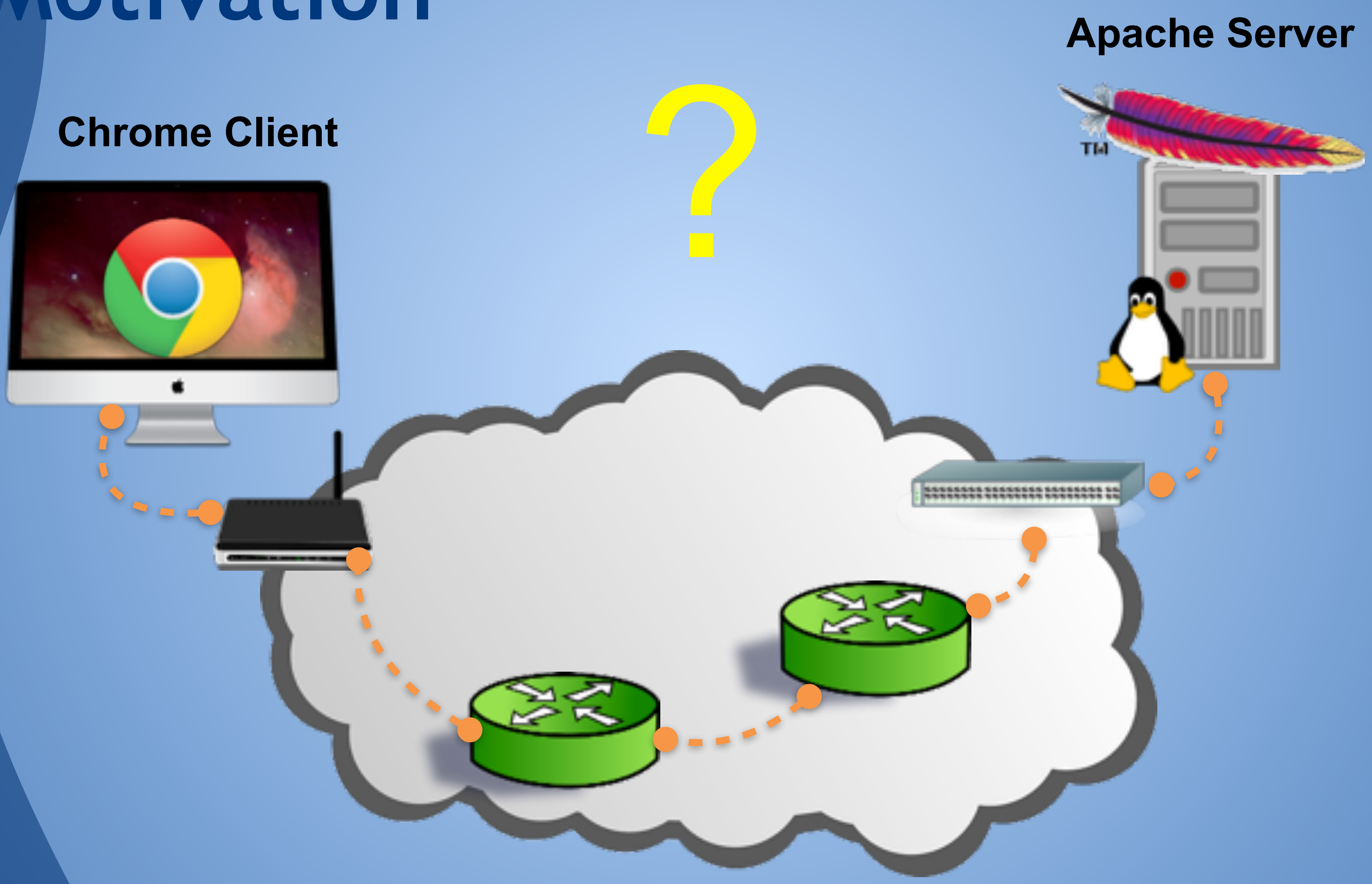
Header
Space
Analysis, etc.
Network Config
Analysis
Chrome Client
Apache Server
Model &
Config
Model &
Config
Model &
Config
Model &
Config

Motivation

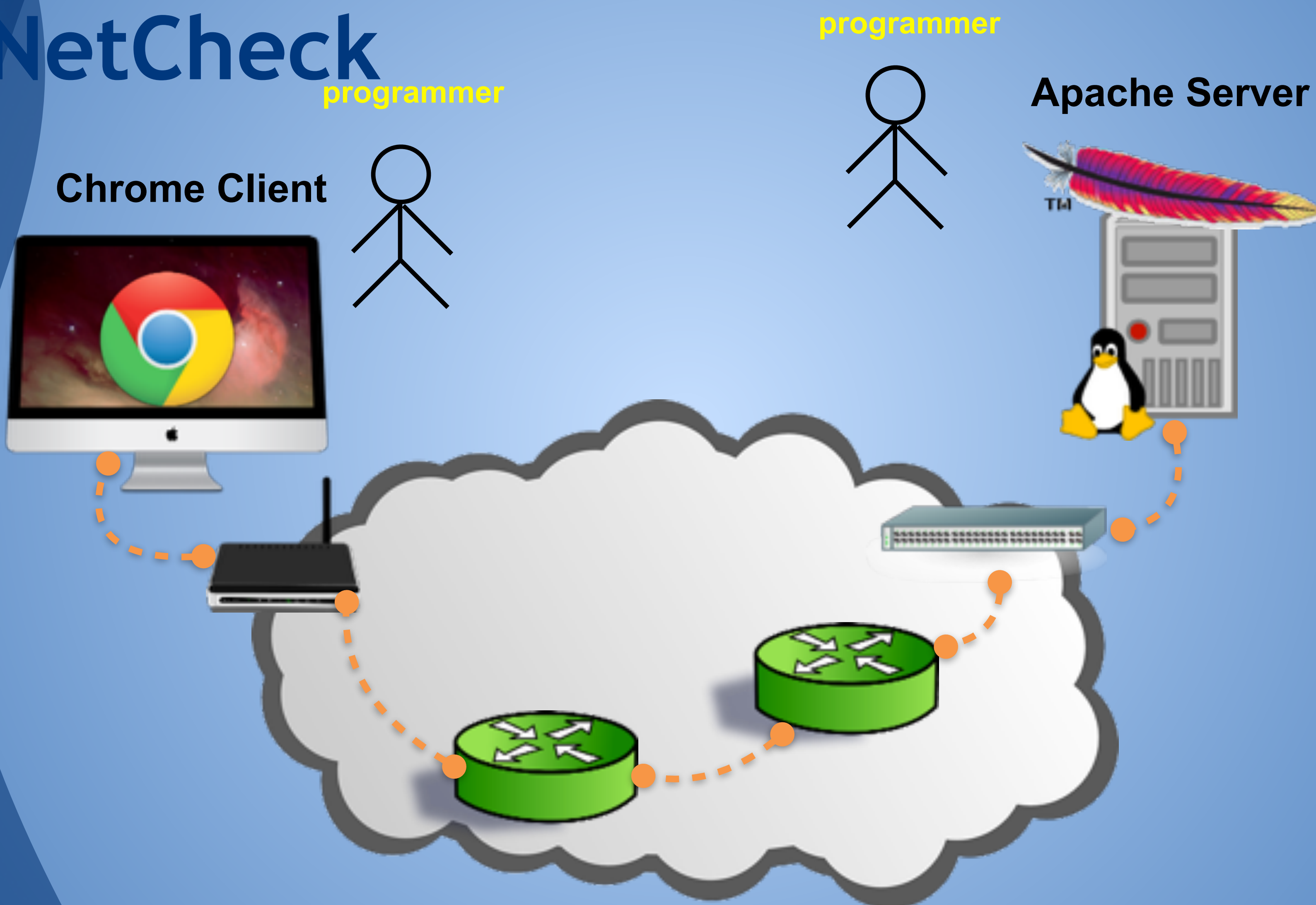
Need detailed
network knowledge
HW + config



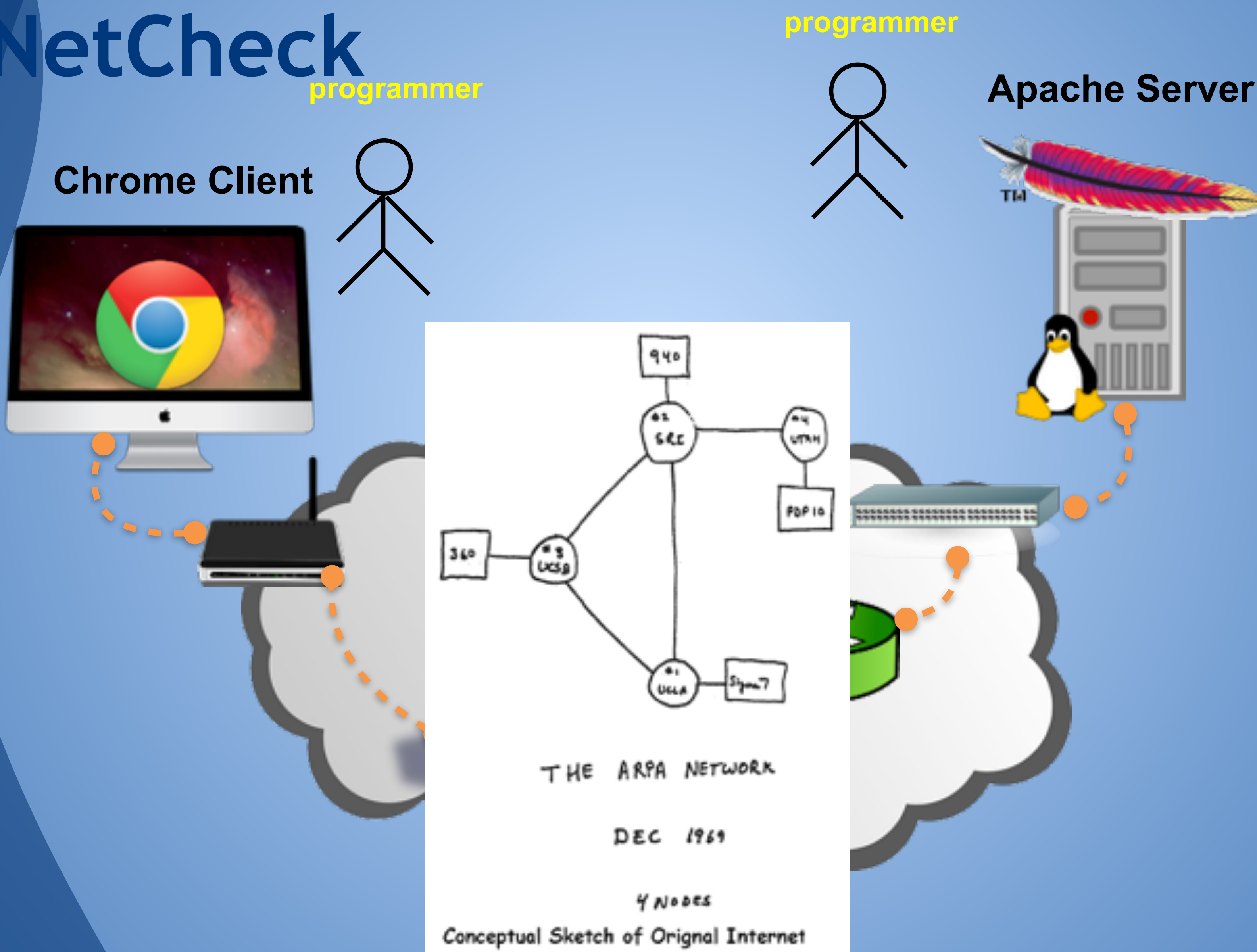
Motivation



NetCheck

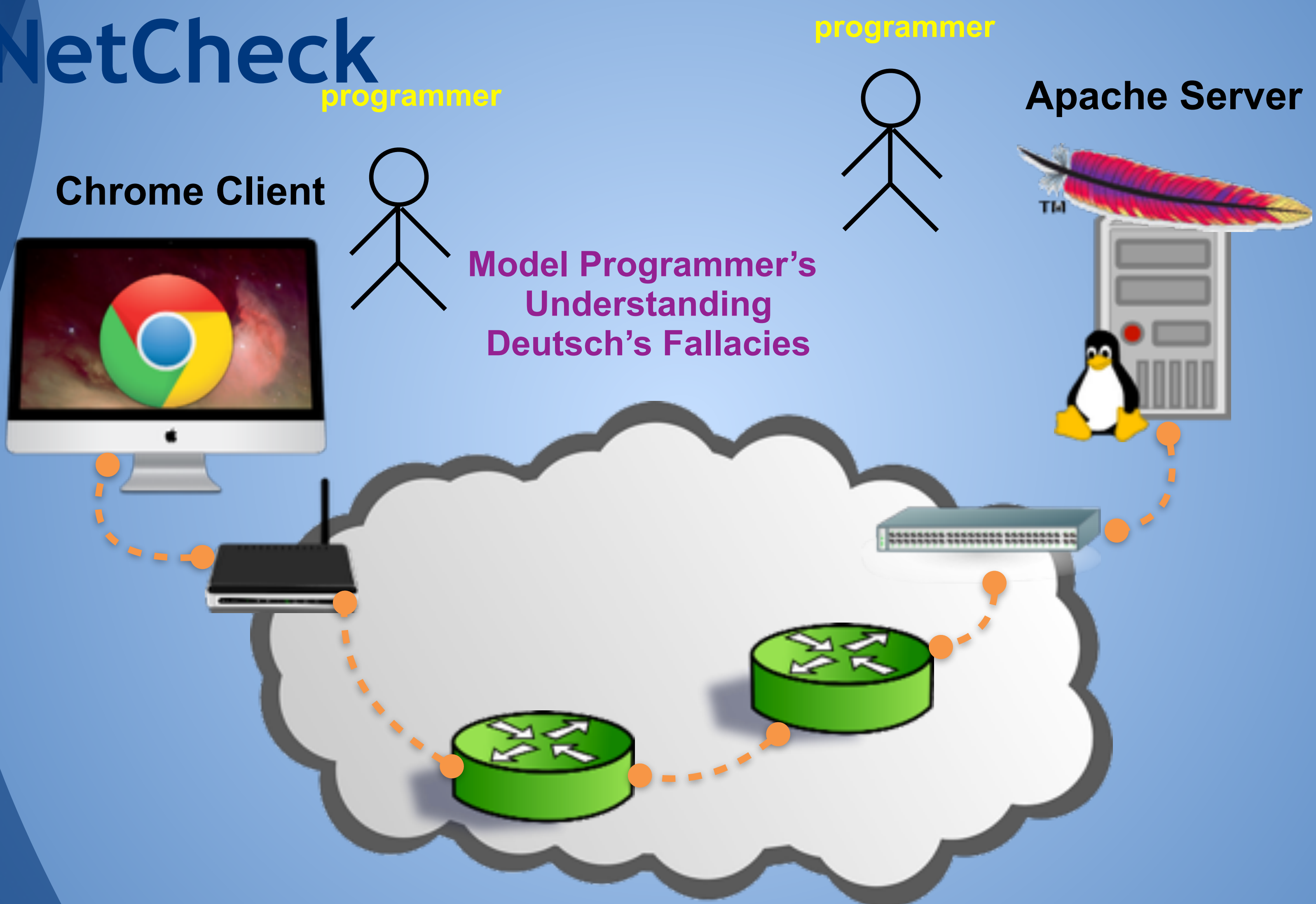


NetCheck



programmer
programmer
Apache Server
Chrome Client
940
#2 SRI
#4 UTAH
PDP 10
360
#3 UCSB
#1 UCLA
Sigma 7
THE ARPA NETWORK
DEC 1969
4 NODES
Conceptual Sketch of Orignal Internet

NetCheck


programmer
programmer
Apache Server
Chrome Client
Model Programmer's
Understanding
Deutsch's Fallacies

Outline

- Motivation
- NetCheck Overview
- Trace Ordering
- Network Model
- Fault Classification
- Results / Conclusion

NetCheck overview

Application

↓

Traces

↓

NetCheck

↓

Likely Faults

NetCheck overview

Application

↓

Traces

↓

NetCheck

↓

Likely Faults

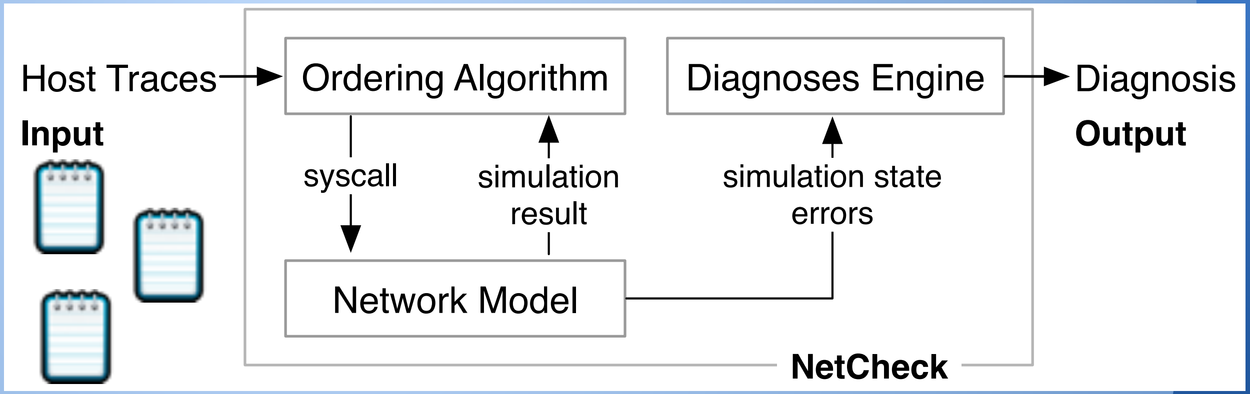
NetCheck overview

Application

Traces

NetCheck

Likely Faults



NetCheck overview

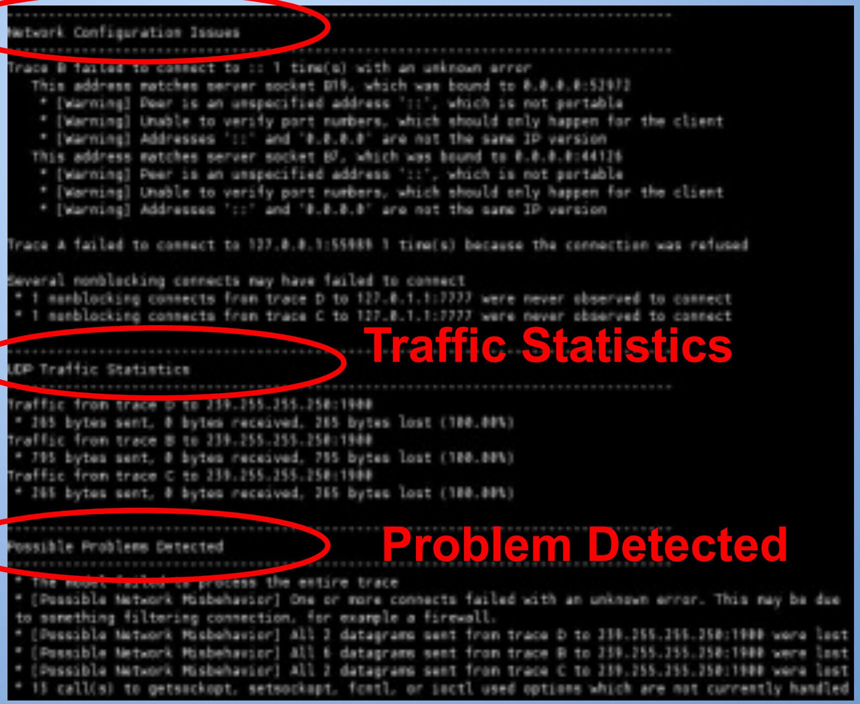
Application

Traces

NetCheck

Likely Faults

Network Configuration Issues



Traffic Statistics

Problem Detected

Outline

- Motivation
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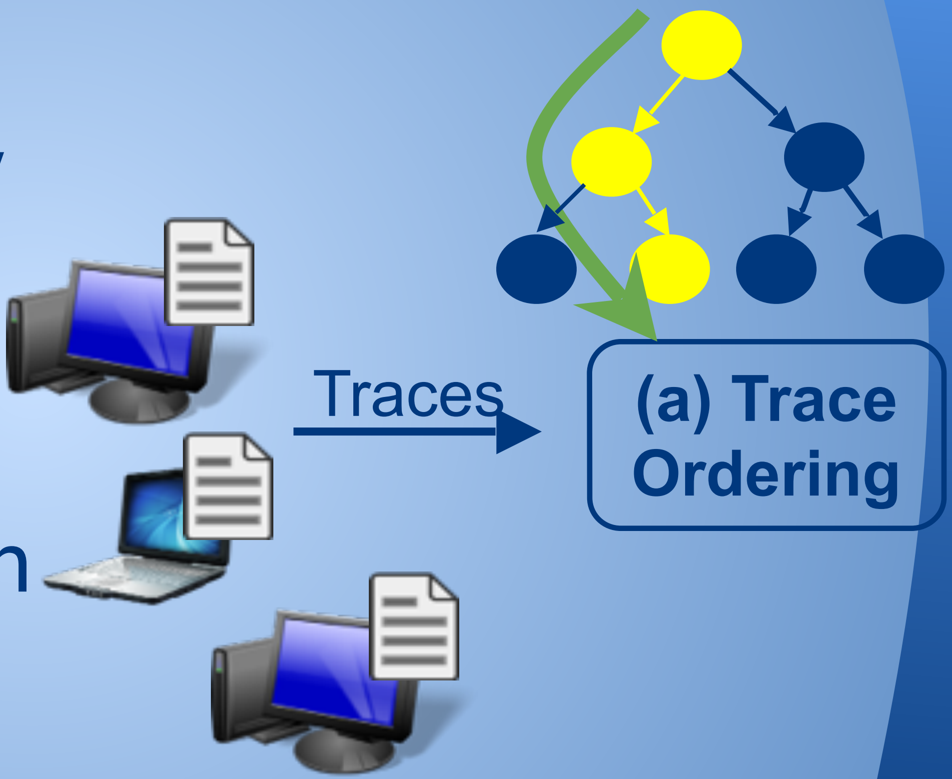
- Fault Classification
- Results / Conclusion



Traces

Series of locally ordered system calls

- Don't want to modify apps or use a global clock
- Gathered by strace, ktrace, systrace, truss, etc.

Call arguments and "return values"

```
socket()            = 3
bind(3, …)          = 0
listen(3, 1)        = 0
accept(3, …)        = 4
recv(4, "HTTP", …)  = 4
close(4)            = 0
```

Call arguments

Return values

Return buffer

What we see is this:

Node A

1. socket() = 3
2. bind(3, ...) = 0
3. listen(3, 1) = 0
4. accept(3, ...) = 4
5. recv(4,"Hello", ..) = 5
6. close(4) = 0

Node B

1. socket() = 3
2. connect(3,...) = 0
3. send(3, "Hello",.) = 5
4. close(3) = 0

- one trace per host
- local order but no global order
Q: how do we reconstruct what really happened?

What we want is this

A1. socket() = 3
B1. socket() = 3
A2. bind(3, .. .) = 0
A3. listen(3, 1) = 0
B2. connect(3,...) = 0
A4. accept(3, ...) = 4
B3. send(3, "Hello", ...) = 5
A5. recv(4, "Hello", ...) = 5
B4. close(3) = 0
A6. close(4) = 0

The ground truth

What we want is this

A1. socket() = 3
B1. socket() = 3
A2. bind(3, .. .) = 0
A3. listen(3, 1) = 0
B2. connect(3,...) = 0
A4. accept(3, ...) = 4
B3. send(3, "Hello", ...) = 5
A5. recv(4, "Hello", ...) = 5
B4. close(3) = 0
A6. close(4) = 0

The ground truth

A

B

Goal: find <u>an equivalent</u> *interleaving*

Observation 1: Order Equivalence

Node A 

1. socket() = 3
2. bind(3, ...) = 0
3. listen(3, 1) = 0
4. accept(3, ...) = 4
5. recv(4,"Hello", ..) = 5
6. close(4) = 0

Node B 

1. socket() = 3
2. connect(3,...) = 0
3. send(3, "Hello",.) = 5
4. close(3) = 0

- one trace per host

- local order but no global order

Q: how do we reconstruct what really happened?

The socket() calls are not visible to the other side

Some orders are equivalent!

Observation 2: Return Values Guide Ordering

Node A 

1. socket() = 3
2. bind(3, ...) = 0
3. listen(3, 1) = 0
4. accept(3, ...) = 4
5. recv(4,"Hello", ..) = 5
6. close(4) = 0

Node B 

1. socket() = 3
2. connect(3,...) = 0
3. send(3, "Hello",.) = 5
4. close(3) = 0

- one trace per host

- local order but no global order

Q: how do we reconstruct what really happened?

Return values guide ordering

A2. bind(3, ...)   = 0
A3. listen(3, 1)   = 0
B2. connect(3, ...) = 0

One valid ordering: all syscalls returned successfully.

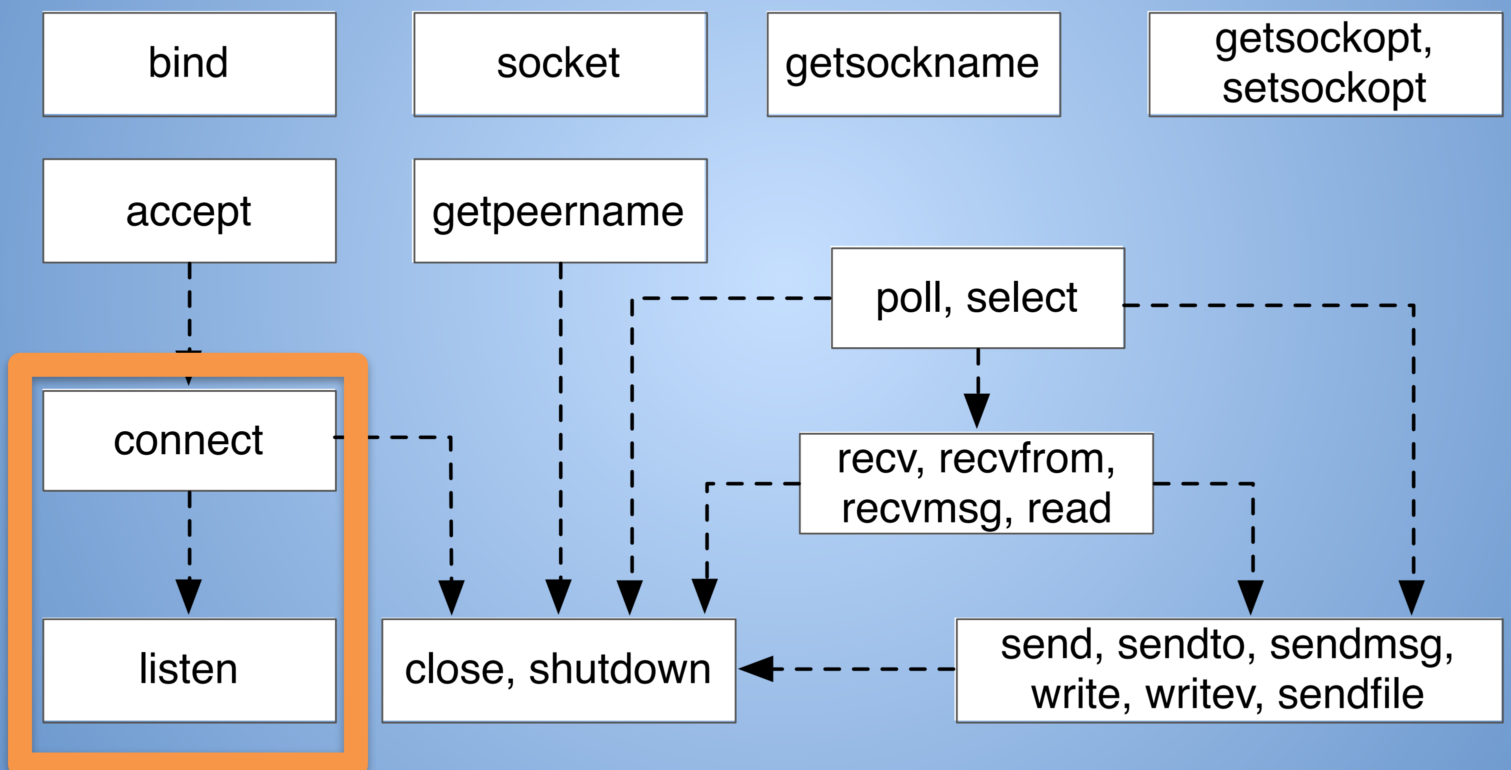
A2. bind(3, ...)   = 0
B2. connect(3, ...) = -1, ECONNREFUSED
A3. listen(3, 1)   = 0

A second valid ordering: connect failed with ECONNREFUSED.

A call's return value may-depend-on a remote call's action

Result indicates order of calls

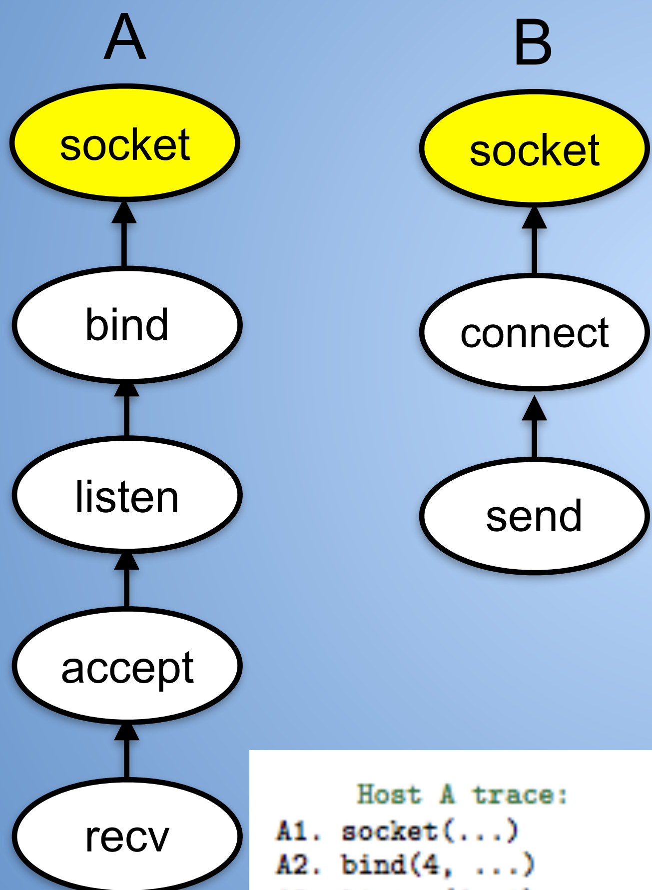
Deciding call order



full set of may-depend-on relations

Ordering Algorithm

Input traces



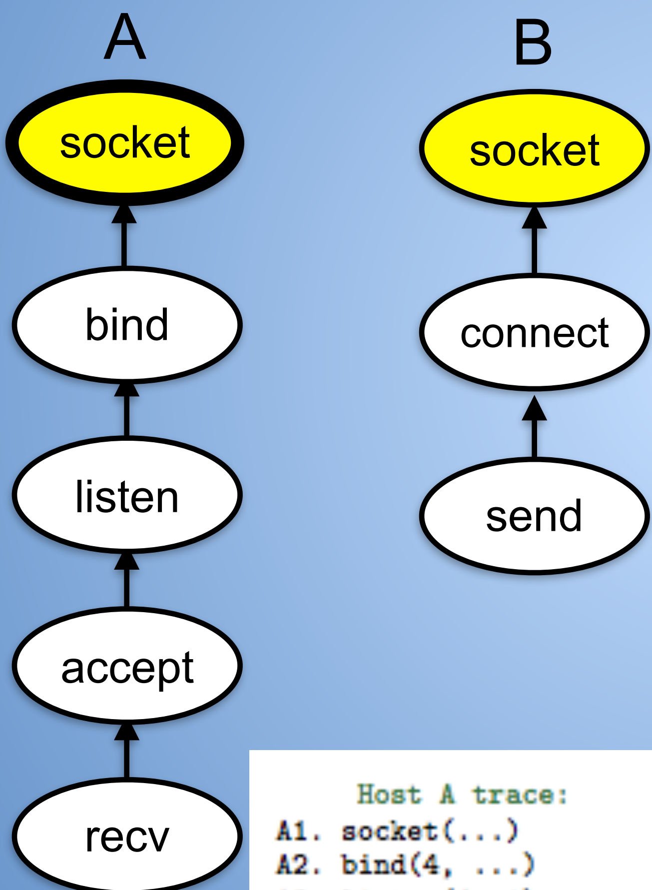
Algorithm process

Output Ordering

```
     Host A trace:                          Host B trace:
A1. socket(...)              = 4      B1. socket(...)            = 3
A2. bind(4, ...)             = 0      B2. connect(3, ...)        = 0
A3. listen(4, 1)             = 0      B3. send(3, "Hello", ...) = 5
A4. accept(4, ...)           = 6
A5. recv(6, "Hola!", ...)    = 5
```

Ordering Algorithm

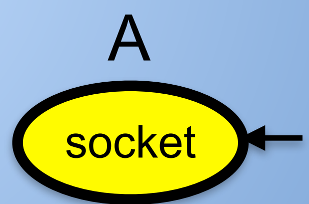
Input traces



Algorithm process

Try socket on host A: **accepted**

Output Ordering




```
        Host A trace:                         Host B trace:
A1. socket(...)          = 4       B1. socket(...)             = 3
A2. bind(4, ...)         = 0       B2. connect(3, ...)         = 0
A3. listen(4, 1)         = 0       B3. send(3, "Hello", ...) = 5
A4. accept(4, ...)       = 6
A5. recv(6, "Hola!", ...) = 5
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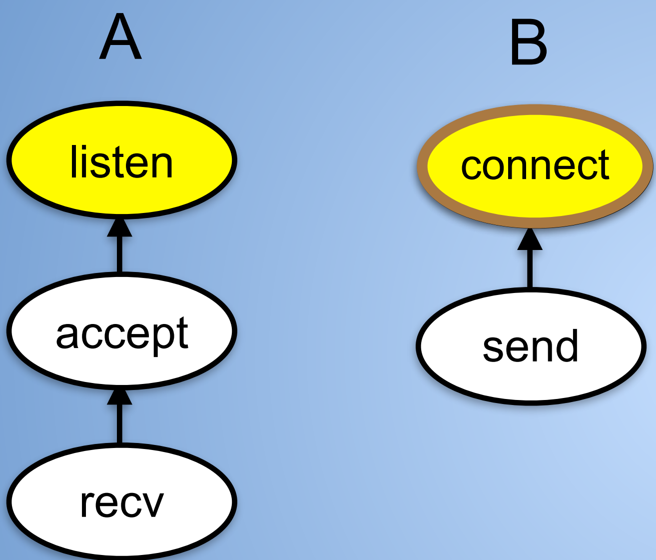
Ordering Algorithm

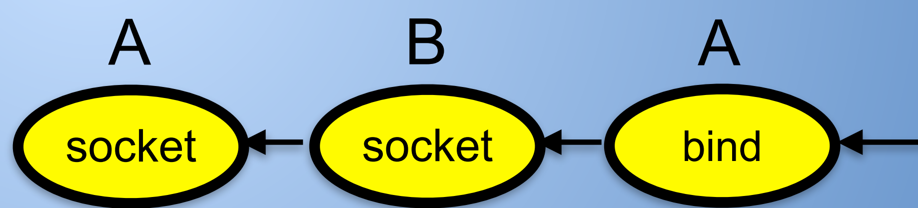
Input traces



Algorithm process

Try connect on host B: **rejected**

Output Ordering




```
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A1. socket(...)          = 4         B1. socket(...)          = 3
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A3. listen(4, 1)         = 0         B3. send(3, "Hello", ...) = 5
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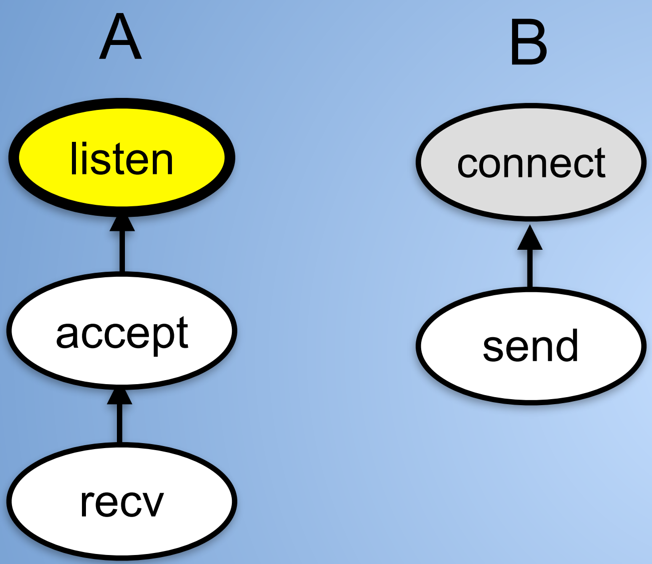
A5. recv(6, "Hola!", ...) = 5
```

Ordering Algorithm

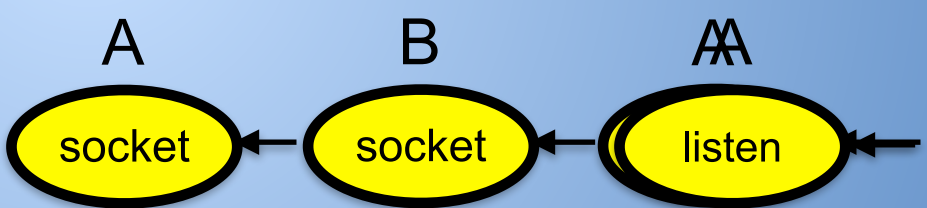
Input traces



Algorithm process

Try listen on host A: **accepted**

Output Ordering




```
     Host A trace:                        Host B trace:
A1. socket(...)           = 4    B1. socket(...)           = 3
A2. bind(4, ...)          = 0    B2. connect(3, ...)       = 0
A3. listen(4, 1)          = 0    B3. send(3, "Hello", ...) = 5
A4. accept(4, ...)        = 6
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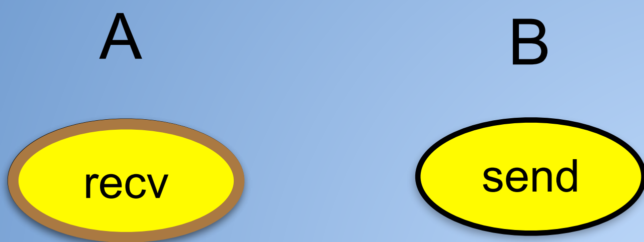
Ordering Algorithm

Input traces

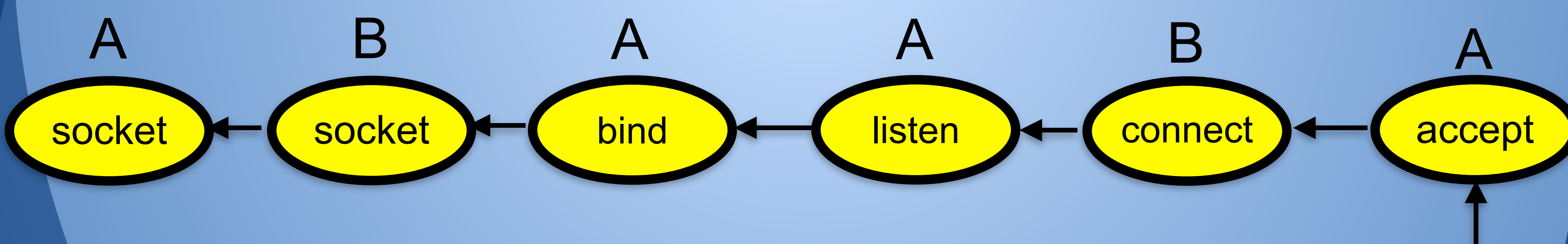


Algorithm process

Try recv on host A: **rejected**

TCP BUFFER: “”

Output Ordering

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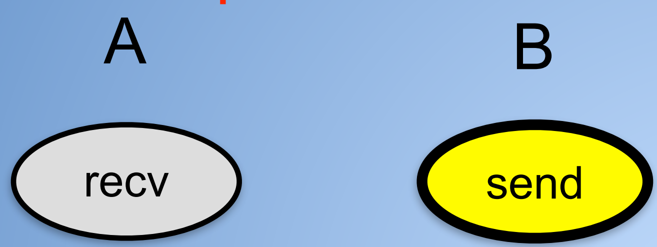
Ordering Algorithm

Input traces

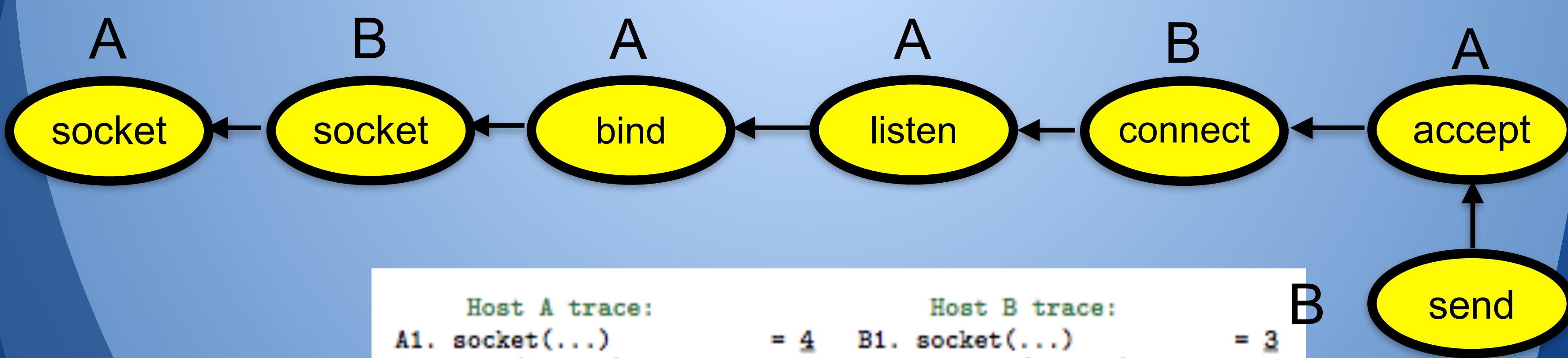


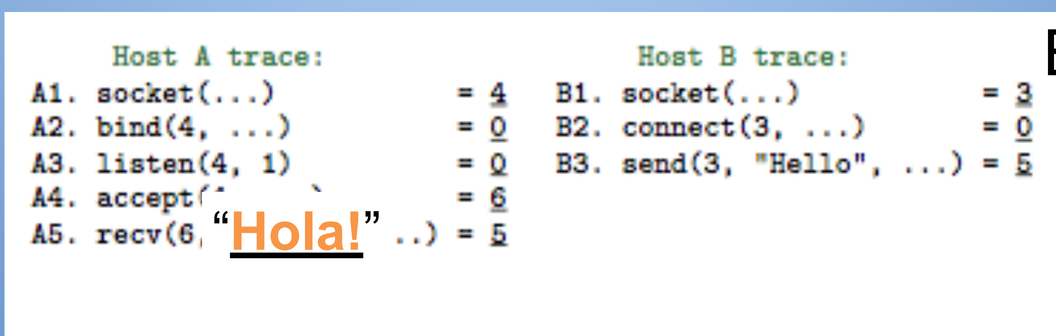
Algorithm process

Try send on host B: **accepted**

TCP BUFFER: “”

Output Ordering





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A4. accept(              = 6
A5. recv(6, “Hola!” ..)  = 5
```

Ordering Algorithm

Input traces

A

recv

B

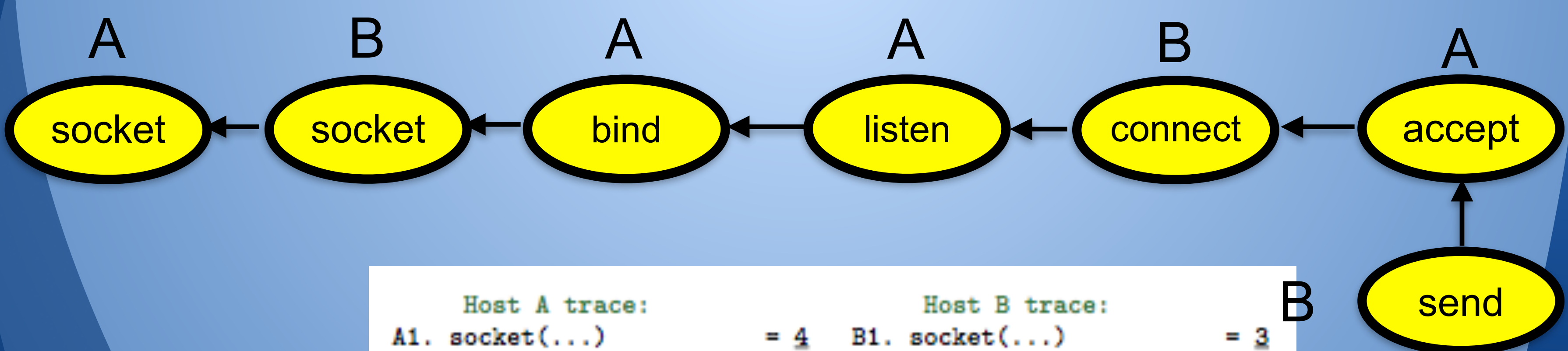
None

TCP BUFFER: "**Hello**"

Algorithm process

Try send on host B: **accepted**

Output Ordering

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A3. listen(4, 1)         = 0     B3. send(3, "Hello", ...)  = 5
A4. accept(               = 6
A5. recv(6, "Hola!" ..)  = 5
```

Ordering Algorithm

Input traces

A B

recv None

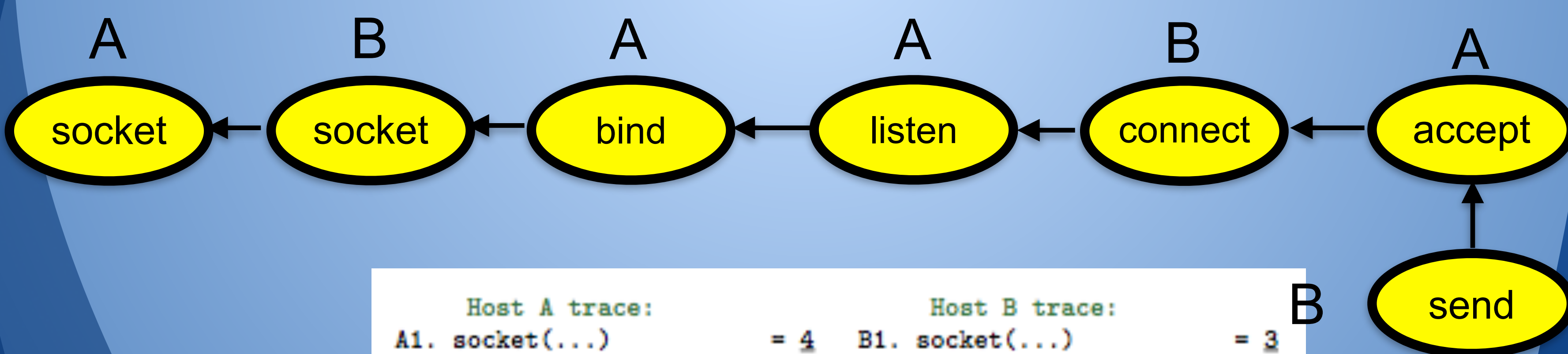
TCP BUFFER: “Hello”

Algorithm process

Try recv on host A:

Fatal Error

Output Ordering

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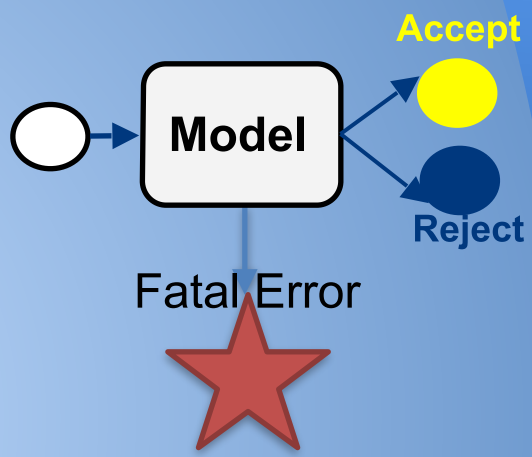
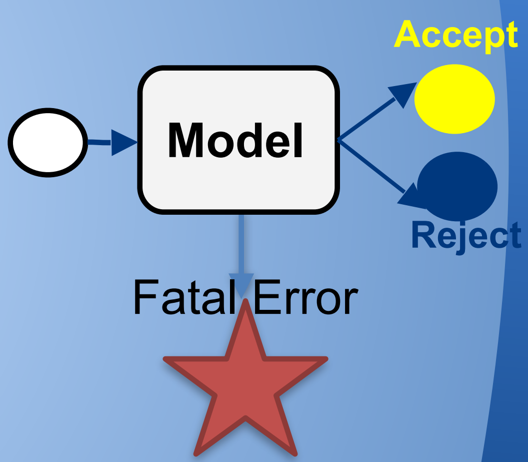
- Fault Classification
- Results / Conclusion



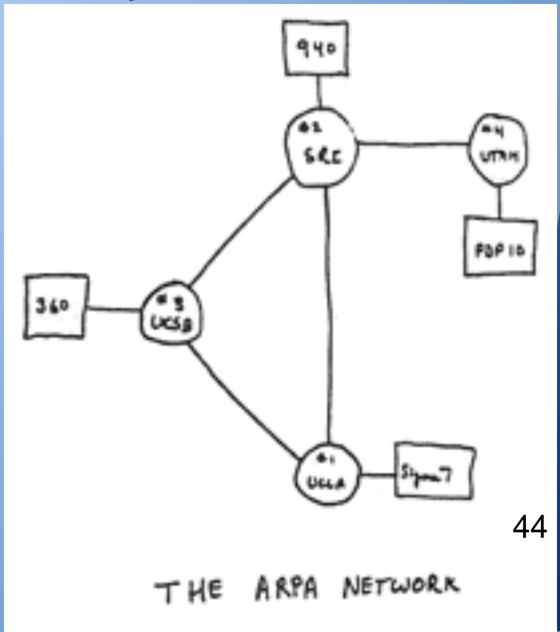
Network Model

- Simulates invocation of a syscall
  - datagrams sent/lost
    - reordering / duplication is notable
  - track pending connections
  - buffer lengths and contents
    - send -> put data into buffer
    - recv -> pop data from buffer
- Simulation outcome
  - *Accept* → can process (correct buffer)
  - *Reject* → wrong order (incomplete buffer)
  - *Permanent reject* → abnormal behavior (incorrect buffer)



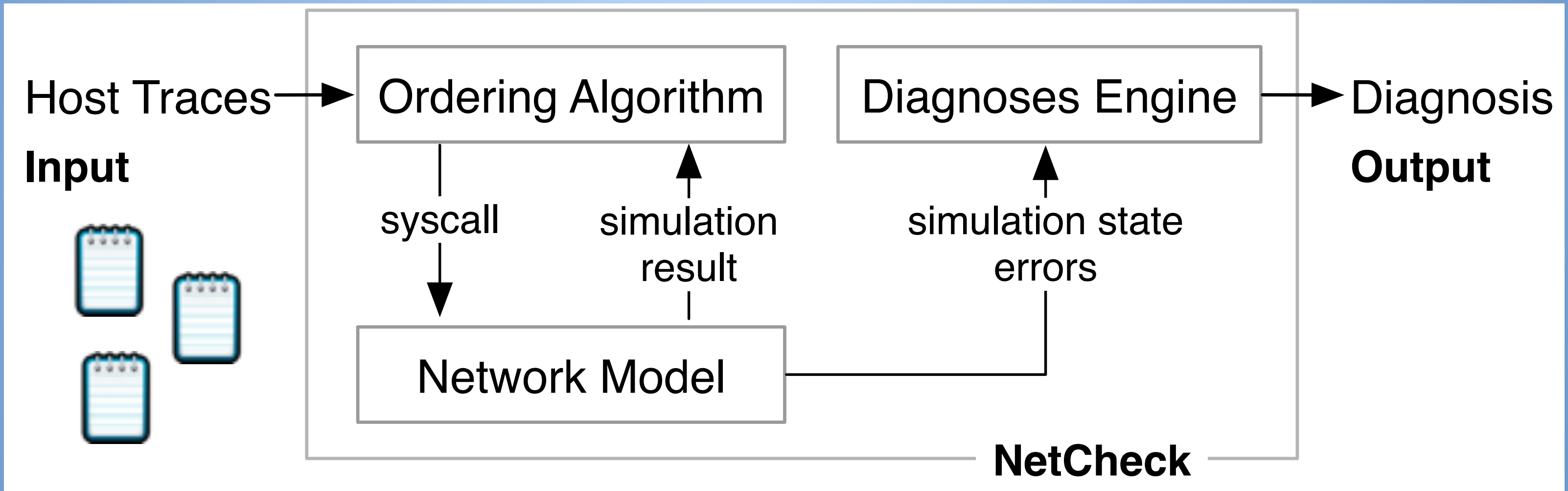
Network Model

- Simulates invocation of a syscall
- Capture programmer assumptions
  - Assumes a simplified network view
    - Assume transitive connectivity
    - Little, random loss
    - No middle boxes
  - Assume uniform platform
    - Flag OS differences



How Model Return Values Impact Trace Ordering

- Blackbox Tracing mechanism



Trace Ordering: linear running time (total trace length) * number of traces

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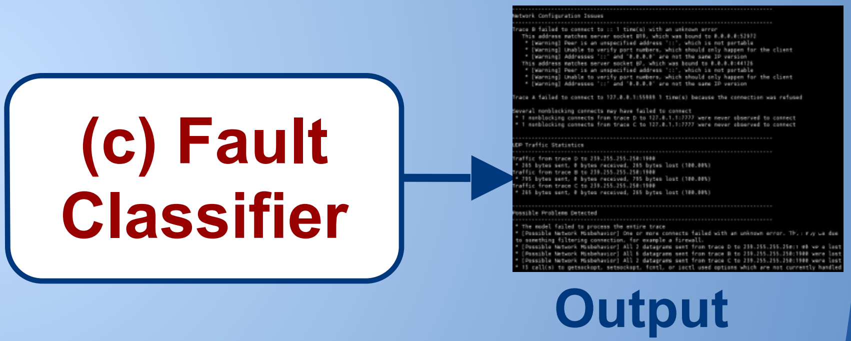
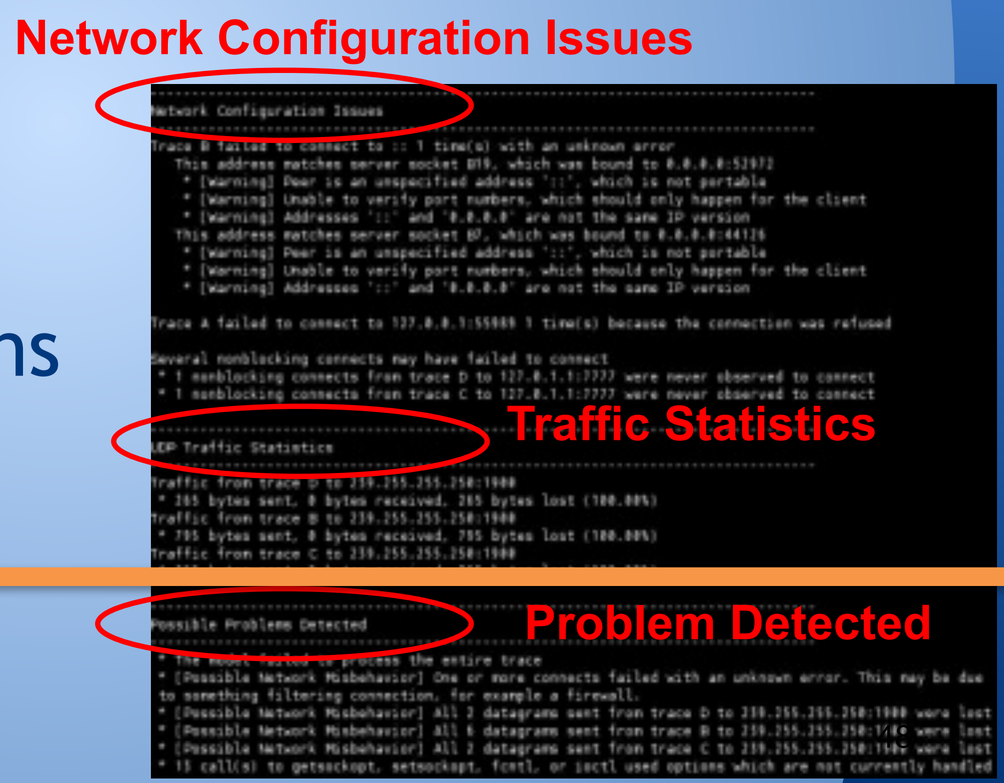


Fault Classifier

- Goal: Decide what to output
- Problem: Show relevant information
- Fault classifier: global (rather than local) view
  - uncovers high-level patterns by extracting low-level features
    - Examples: middleboxes, non-transitive connectivity, MTU, mobility, network disconnection
    - All look like loss, but have different patterns in the context of other flows

Fault Classifier

- Options to show different levels of detail
- Network admins / developers
  - detailed info
- End users
  - Classification
  - Recommendations



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Evaluation: Production Application Bugs

- Reproduce reported bugs from bug trackers (Python, Apache, Ruby, Firefox, etc.)
  - A total of 71 bugs
  - Grouped into 23 categories
    - Virtualization incurred/portability bugs
    - SO_REUSEADDR behaves differently across OSes
    - accept inherit O_NONBLOCK
    - …
  - Correct analysis of >95% bugs

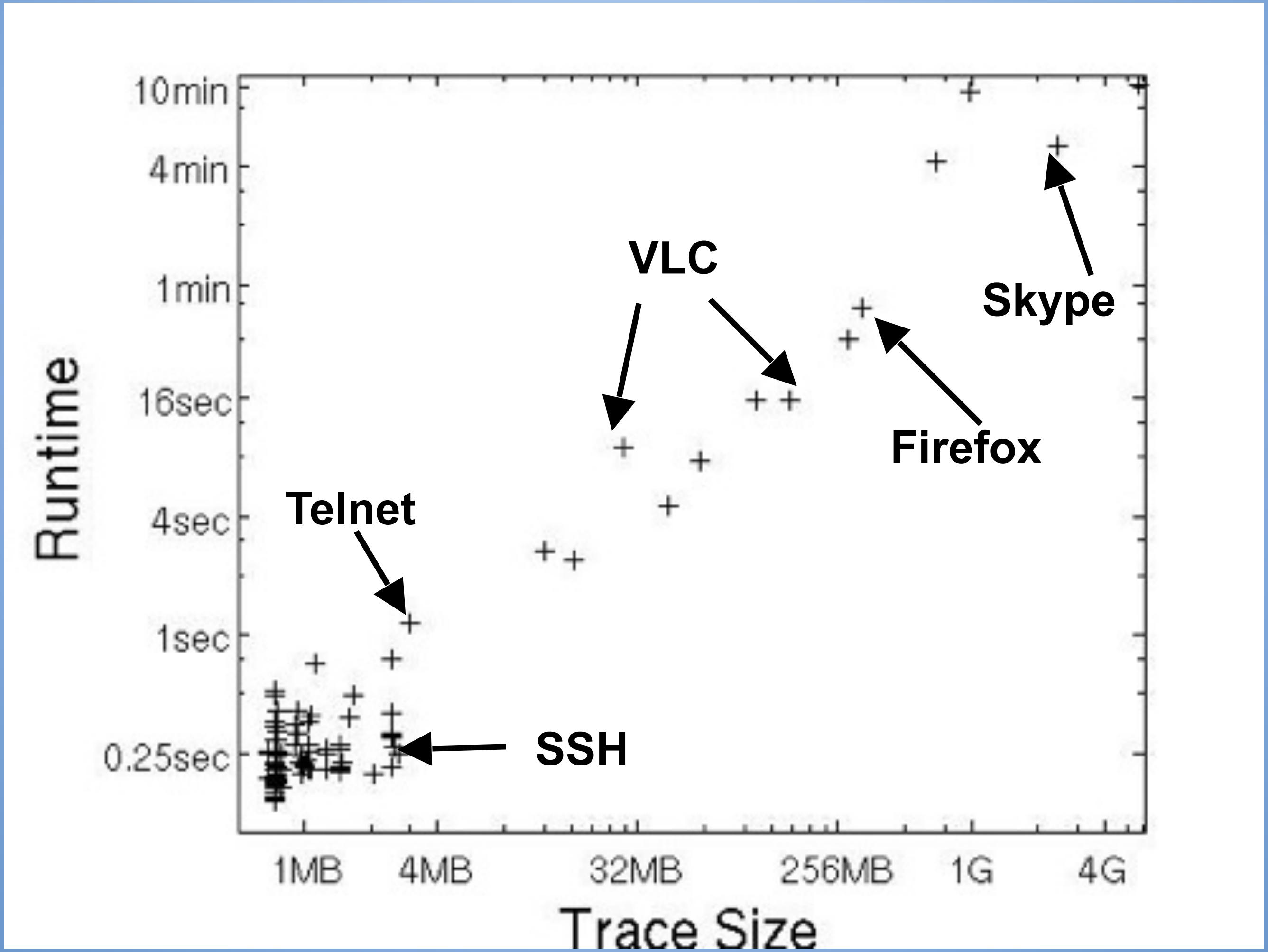
Evaluation: Observed Network Faults

- Twenty faults observed in practice on a live network
  - MTU bug
    - Intermediary device
  - Port forward
    - Traffic sent to non-relevant addresses
  - Provide supplemental info
    - packet loss
    - buffers being closed with data in
  - 90% of cases correctly detected

General Findings in Practice

- Middle boxes
  - Multiple unaccepted connections
    - client behind NAT in **FTP**
- TCP/UDP
    - non-transitive connectivity in **VLC**
- Complex failures
  - **VirtualBox** send data larger than buffer size
  - **Pidgin** returned IP different from bind
  - **Skype** NAT + close socket from a different thread
- Used on Seattle Testbed seattle.poly.edu

NetCheck Performance Overhead



Conclusion

Built and evaluated NetCheck, a tool to diagnose network failures in complex apps

- Key insights:
  - model the programmer's misconceptions
  - relation between calls → reconstruct order
- NetCheck is effective
  - Everyday applications & networks
  - Real network / application bugs
  - No per-network knowledge
  - No per-application knowledge

Try it here: https://netcheck.poly.edu/