Automatically Generating Predicates and Solutions for Configuration Troubleshooting

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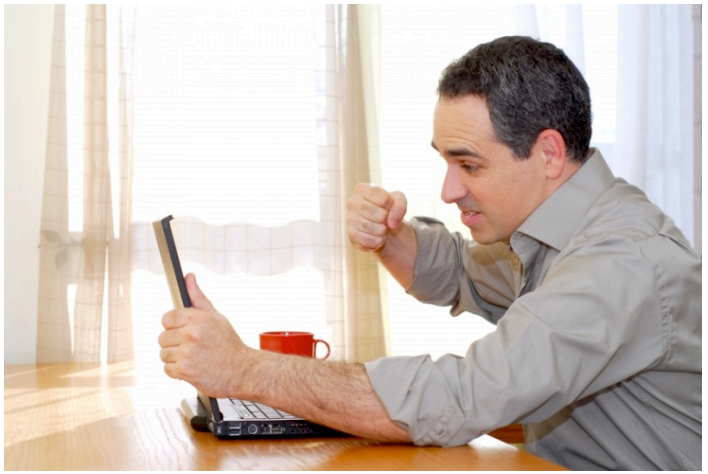
Troubleshooting misconfigurations is hard!

- Users may have to
  - Edit configuration files
  - Resolve library dependencies
  - Change environment variables



- Automated troubleshooting tools can help
  - Chronus: finds when a misconfiguration entered
  - AutoBash: automatically resolves misconfigurations
  - Both assume test cases or solutions exist

Current method: manual predicate creation

- Predicates
  - Test if an application works or not
  - Returns true/false if the test passes/fails
- E.g. test if an Apache Web server is working

```
wget http://localhost
```

- Manually writing predicates requires
  - Experts and time
  - Domain knowledge
- Can we automatically generate predicates?

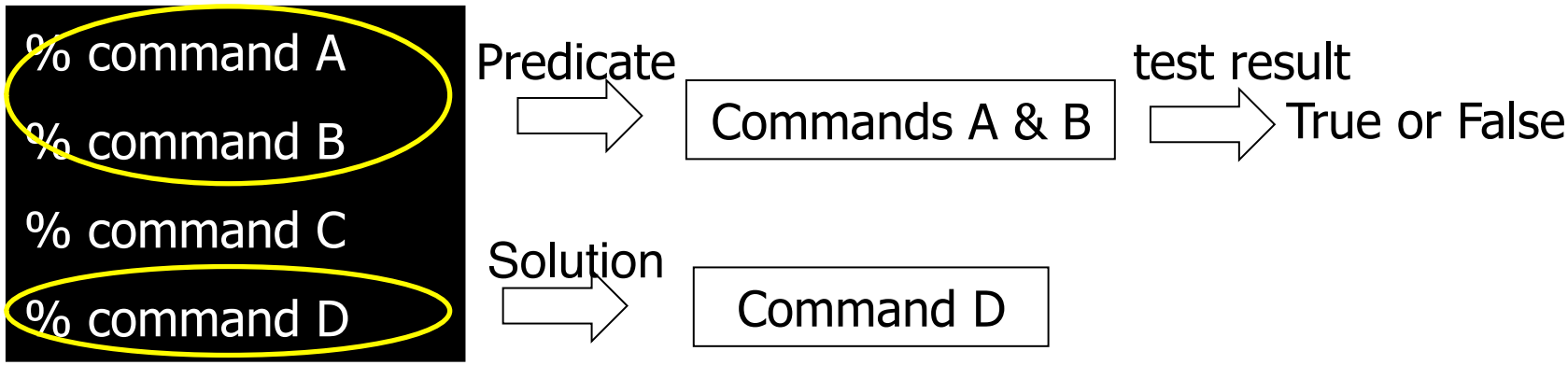
Limitations in existing approaches

- Automatic test case generation requires
  - Program source code or specifications
- Automatic solution generation requires
  - Golden state as a reference

- Users already troubleshoot misconfigurations
  - They try potential solutions
  - They test if a solution works

Valuable source to generate predicates/solutions for others to use

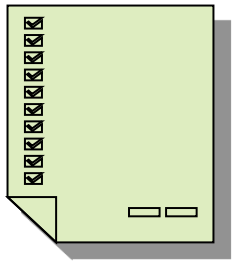
Generating predicates from user traces



- Users troubleshoot using our modified shell
- Our modified shell generates:
  - Which command is a predicate
  - If a predicate succeeds/fails
  - Which commands are solutions

Goals

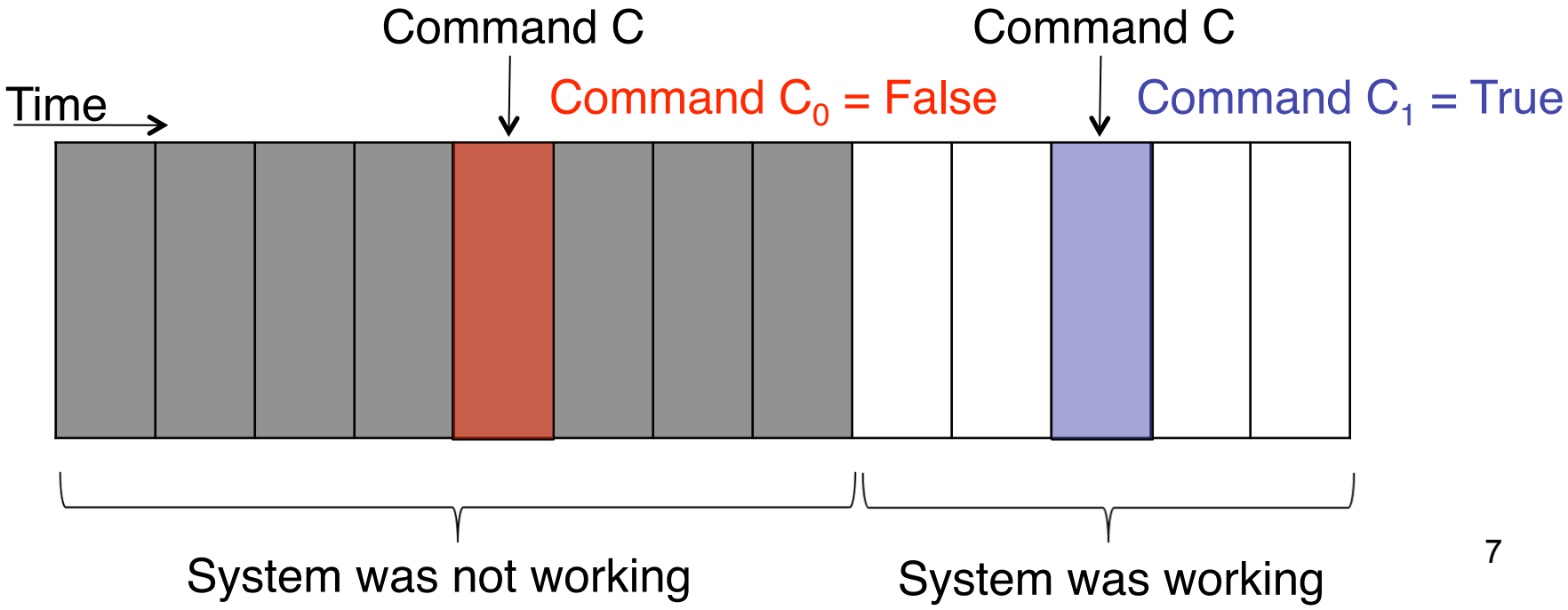
- Minimize false positives
  - A false positive is worse than a false negative
  - Aggregate across multiple user traces
- Be as unobtrusive as possible
  - Users do not need to provide extra input



- Generate complete predicates
  - Predicates may contain multiple steps

Minimizing false positives

- Observation: troubleshooting pattern
  - Users test the system state multiple times
  - Users rely on output to know test outcome
- Generate predicates following this pattern



Our approach

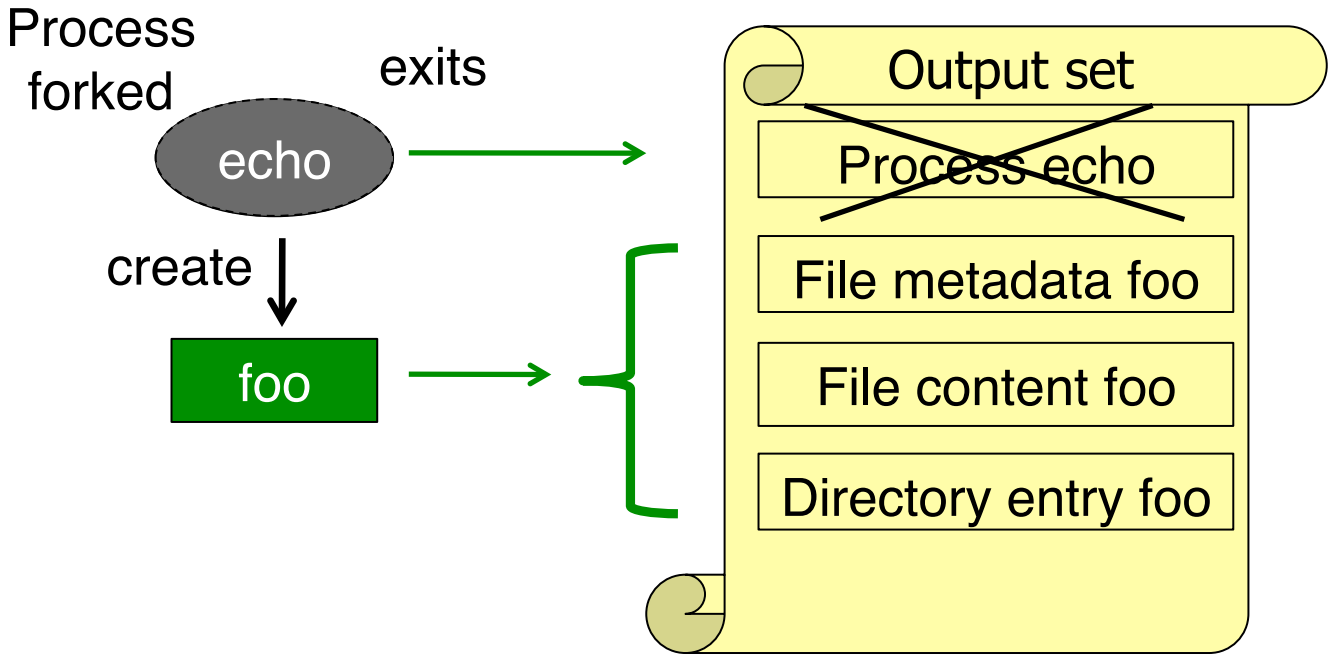
- Predicates
  - Repeated commands
  - Differ in more than two out of three output features
- Output features for a command:
  - exit code: the return value of a process
  - screen output contains error message
  - output set: kernel objects a command modifies

Tracking output sets

- Output set: kernel objects a command causally affects

Command: echo hi > foo

Output set = {file foo}



Example

```
% cvs –d /home/cvsroot import test_project
cvs [import aborted]: /home/cvsroot/CVSROOT:
    No such file or directory

% cvs –d /home/cvsroot init


% cvs –d /home/cvsroot import test_project
N  test_project/testfile
No conflicts created by this import
```

Problem: CVS repository not initialized

Example

```
% cvs –d /home/cvsroot import test_project
cvs [import aborted]: /home/cvsroot/CVSROOT:
    No such file or directory

% cvs –d /home/cvsroot init


% cvs –d /home/cvsroot import test_project
N  test_project/testfile
No conflicts created by this import
```

- Find repeated commands

Example

```
% cvs –d /home/cvsroot import test_project
cvs [import aborted]: /home/cvsroot/CVSROOT:
    No such file or directory

% cvs –d /home/cvsroot init


% cvs –d /home/cvsroot import test_project
N  test_project/testfile
No conflicts created by this import
```

- Compare output features of repeated commands

Example

```
% cvs –d /home/cvsroot import test_project       exit code = 1
cvs [import aborted]: /home/cvsroot/CVSROOT:
   No such file or directory

% cvs –d /home/cvsroot init


% cvs –d /home/cvsroot import test_project       exit code = 0
N  test_project/testfile
No conflicts created by this import
```

Output feature: exit codes differ

Example

```
% cvs –d /home/cvsroot import test_project
cvs [import aborted]: /home/cvsroot/CVSROOT:
   No such file or directory

% cvs –d /home/cvsroot init


% cvs –d /home/cvsroot import test_project
N  test_project/testfile
No conflicts created by this import
```

No error message

- Output feature: screen outputs differ
  - First execution prints error message
  - Second execution does not contain error msg

Example

```
% cvs –d /home/cvsroot import test_project
cvs [import aborted]: /home/cvsroot/CVSROOT:
   No such file or directory                    => Output set = {}

% cvs –d /home/cvsroot init


% cvs –d /home/cvsroot import test_project
N  test_project/testfile                        => Output set = {file:/home/cvsroot/
                                                   test_project, …}
No conflicts created by this import
```

- Output feature: output sets differ
  - First execution: output set is empty
  - Second execution: output set contains created files

Example

```
% cvs –d /home/cvsroot import test_project          => predicate fails
cvs [import aborted]: /home/cvsroot/CVSROOT:
   No such file or directory

% cvs –d /home/cvsroot init


% cvs –d /home/cvsroot import test_project       => predicate succeeds
N  test_project/testfile
No conflicts created by this import
```

- Repeated commands differ in three output features
- First execution considered to be a failed predicate

Generating complete predicates

How?

- Some predicates depend on preconditions to be executed first to work correctly

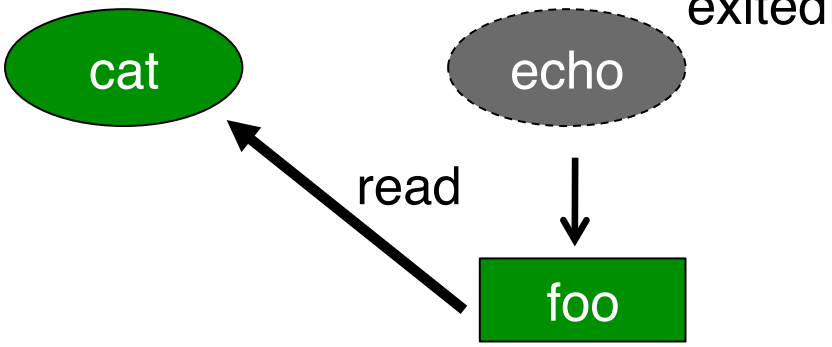
```
user1 % cvs –d /home/cvsroot import test_project        Precondition

user2 % cvs –d /home/cvsroot checkout test_project   => Predicate fails

root % usermod –G cvsgroup user2                      Solution

user2 % cvs –d /home/cvsroot checkout test_project   => Predicate
                                                        succeeds
```

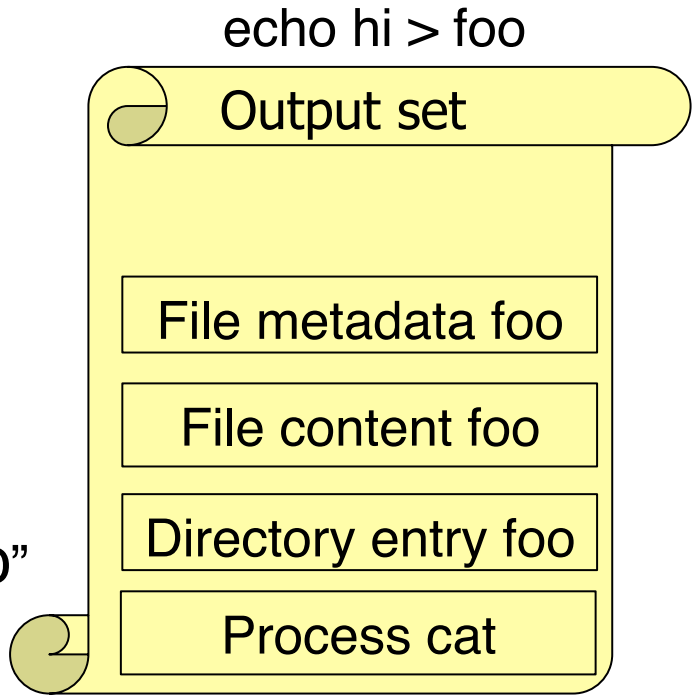
Problem: user2 is not in CVS group

Initial state: CVS repository is empty

Causal relationships between commands

```
% echo hi > foo
%  cat  foo
```





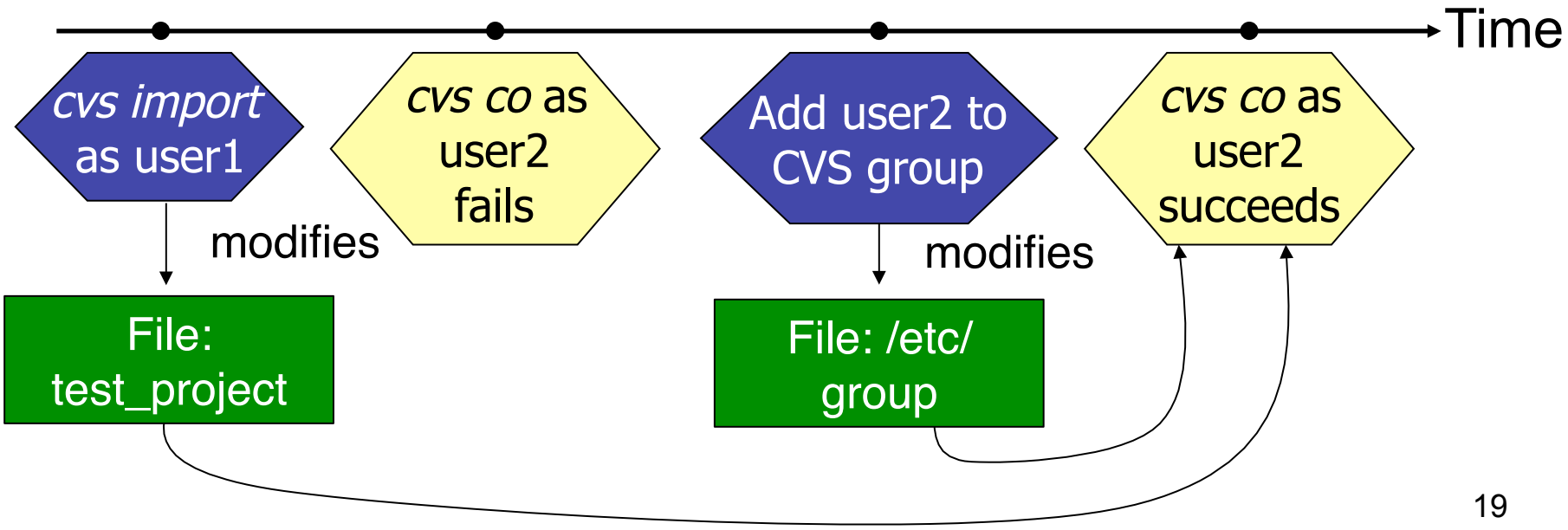
- "cat foo" causally depends on "echo"

  cat is in echo's output set

Applying causality to find preconditions

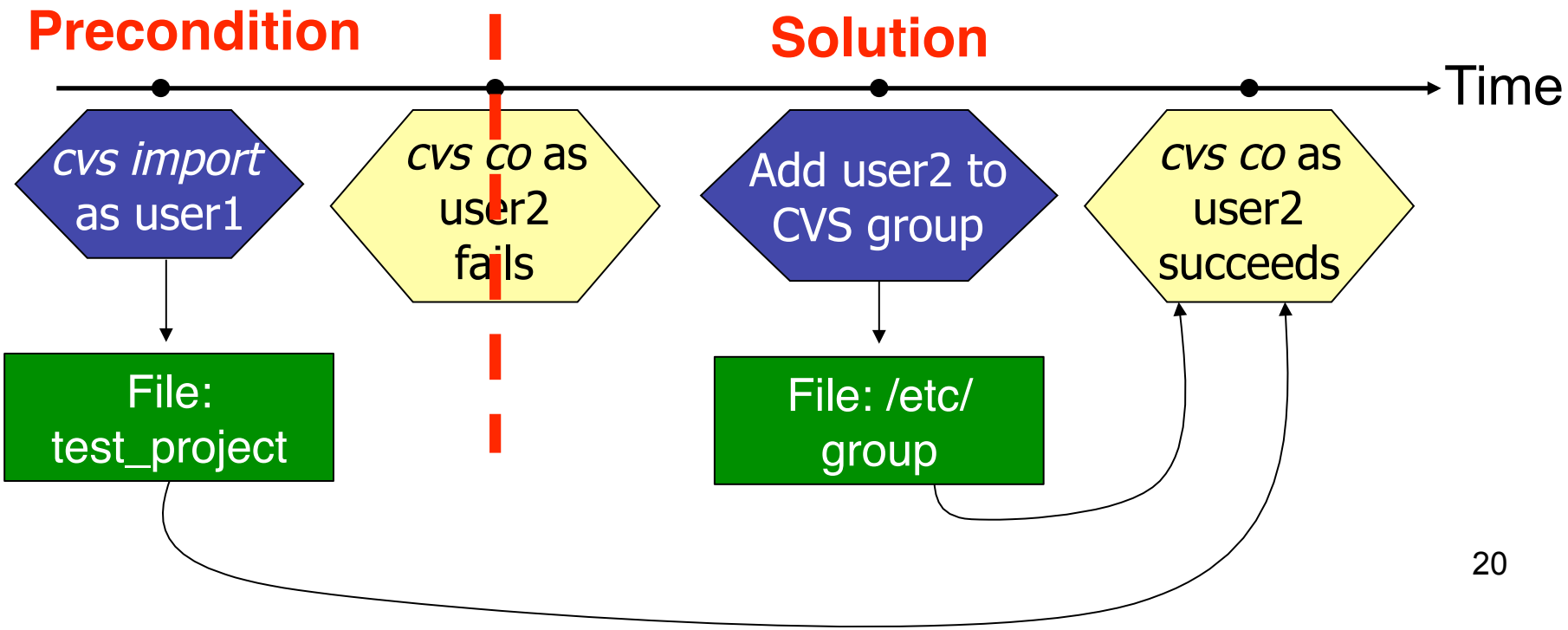
- Candidate preconditions: find
  - All commands a predicate depends on
  - All commands whose output set a predicate is in

We also find solution!



Heuristic to differentiate them

- Solutions: occurred after all failed predicates
- Preconditions:
  - occurred before any failed predicate



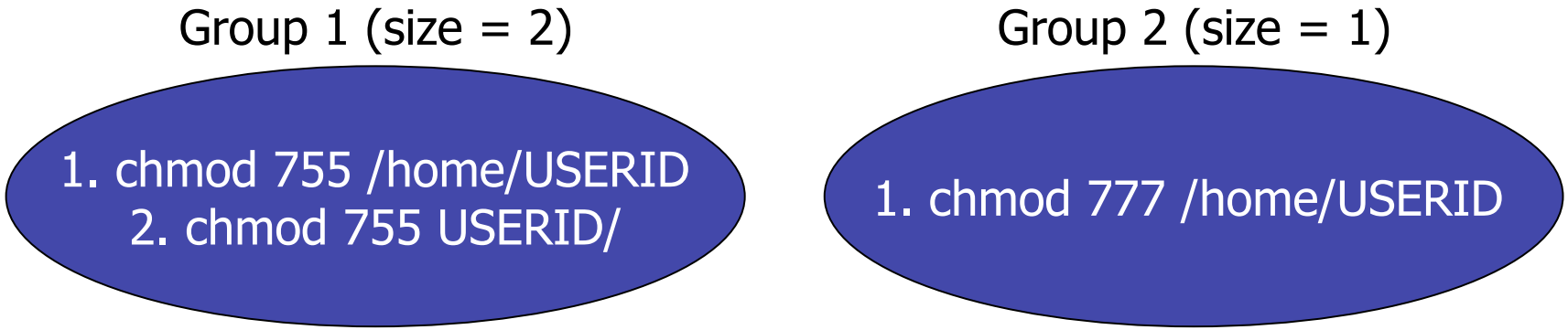
Ranking solutions

- Users solve the same problem differently
- Goal: better solutions are ranked higher
  - Heuristic: solutions applied by more users are better
  - Aggregate solutions among traces and rank them
- Ex. Apache not having search permission
  - chmod 777 /home/USERID
  - chmod 755 USERID/
  - chmod 755 /home/USERID

Different commands can be used to do the same thing.

Group solutions by state delta

- State delta: the difference in system state caused by the execution of a command
  - Track output set for that command
  - Compute diff for each entity in the output set
- Solution ranking results:



Evaluation

- Questions:
  - How well can we generate predicates?
  - How well does the solution ranking heuristic work?

- Methodology
  - Conducted a user study of user troubleshooting
  - Generate predicates/solutions from traces
  - Manually verify predicate correctness

User study procedure

- 12 participants:
  - graduate students
  - system administrators
- Each given four configuration problems
  - Two CVS and two Apache configuration problems
  - Each problem runs in a virtual machine
- Collected traces of users troubleshooting
  - All commands a user typed
  - Collect exit code, screen output, and output set

Predicate result summary

	CVS problem 1	CVS problem 2	Apache problem 1	Apache problem2
# of correct predicates	4	4	6	8
# of wrong predicates	0	0	1	1
Total # of traces	10	10	11	11

- All correct predicates are complete
- Very few wrong predicates (false positives)
- Both false positives come from traces of user not solving the problem
- Why were no predicates generated for some traces?

Apache problem: predicate results

- Problem: Apache process not having search permission on /home/USERID
- Solution: give /home/USERID search permission

Predicates Generated	Number of traces
No predicate generated (User did not use repeated commands)	3
No predicate generated (User did not fix the problem)	2
Incorrect predicate (User did not fix the problem)	1

- To minimize FP, we compare *current directory* and *user id*
- User executed commands in different directories

Apache problem: predicate results

- Problem: Apache process not having search permission on /home/USERID
- Solution: give /home/USERID search permission

Predicates Generated	Number of traces
No predicate generated (User did not use repeated commands)	3
No predicate generated (User did not fix the problem)	2
Incorrect predicate (User did not fix the problem)	1

- User did not fix the problem => output features did not differ

Apache problem: predicate results

- Problem: Apache process not having search permission on /home/USERID
- Solution: give /home/USERID search permission

Predicates Generated	Number of traces
No predicate generated (User did not use repeated commands)	3
No predicate generated (User did not fix the problem)	2
Incorrect predicate (User did not fix the problem)	1

- Predicate: open configuration file in an editor
- Could be eliminated if we asked user whether problem was fixed

Apache problem: solution ranking results

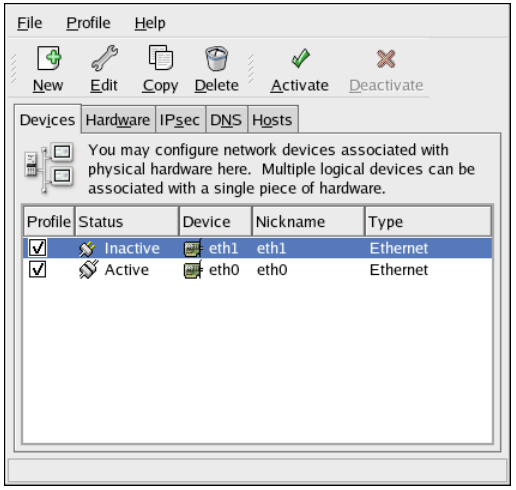
Solution	Number of Traces
chmod 755 /home/USERID	2
chmod –R 777 USERID/	1
chmod o+rx /home/USERID	1
chmod 777 /home/USERID	1
vim /etc/httpd/conf/httpd.conf	1

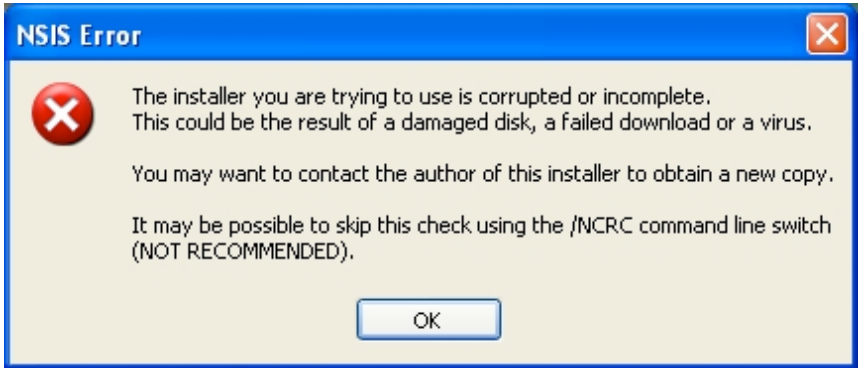
Why is editing configuration file a solution?

- Predicate: *apachectl stop*
- User-introduced errors in conf file caused *apachectl stop* fail

Future work

- Extend this work to handle GUI applications
- Challenges:
  - identifying individual tasks, finding repeated tasks
  - exit code does not map to each task
- Advantages: more semantic information





Conclusion

- Automatically generate predicates and solutions from user troubleshooting traces

- Our approach
  - Minimizes false positives
  - Is unobtrusive to users
  - Generates complete predicates

Thank you!