The Maelstrom: Network Service Troubleshooting Via “Ineffective Procedures”

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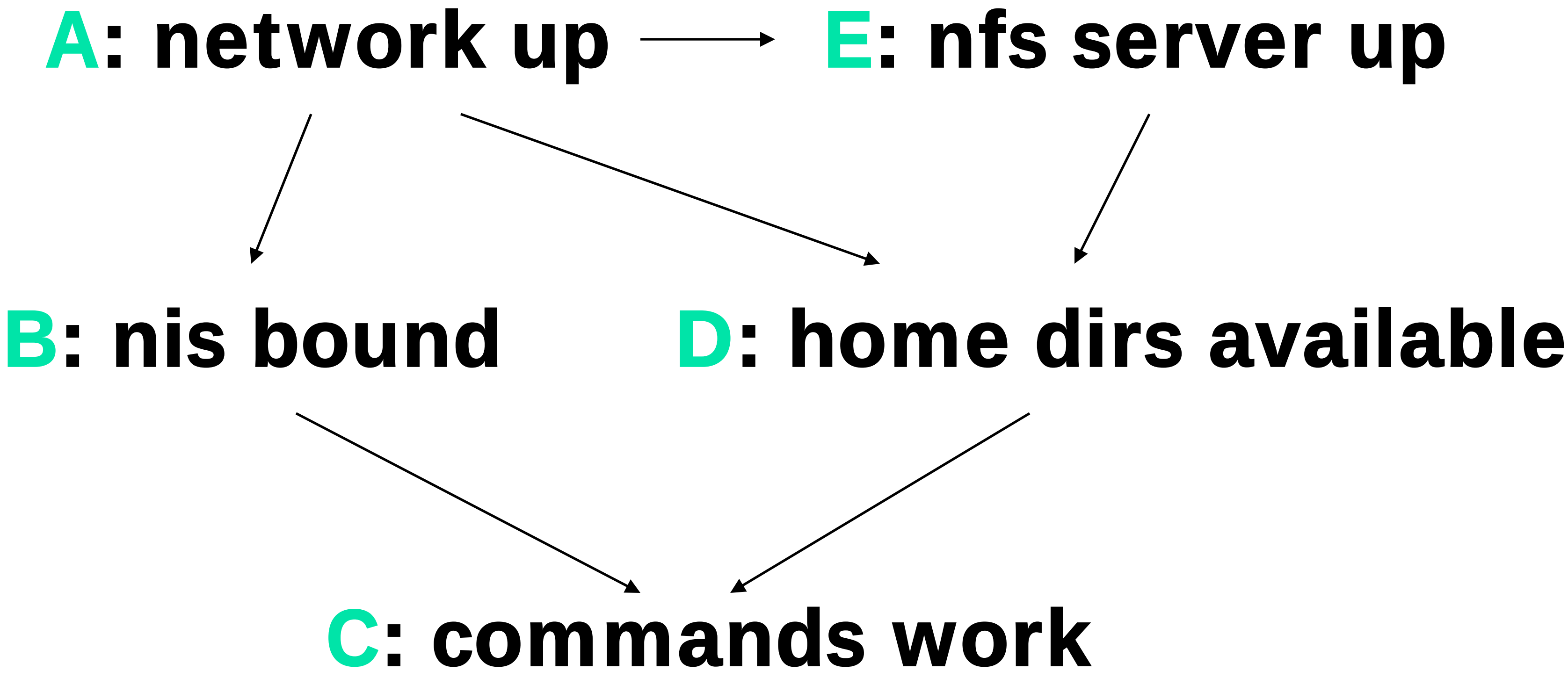
Network Troubleshooting

- Target problem: automate network troubleshooting.
- Starting point: list of services to assure.
- Easy part: how to assure one service.
- Hard part: precedences between assurance tasks.

Dreams

- Quicker response to network problems.
- More collaboration.
- Less “boring” work.
- Acceptable losses!

Silly Example



A: network up

E: nfs server up

B: nis bound

D: home dirs available

C: commands work

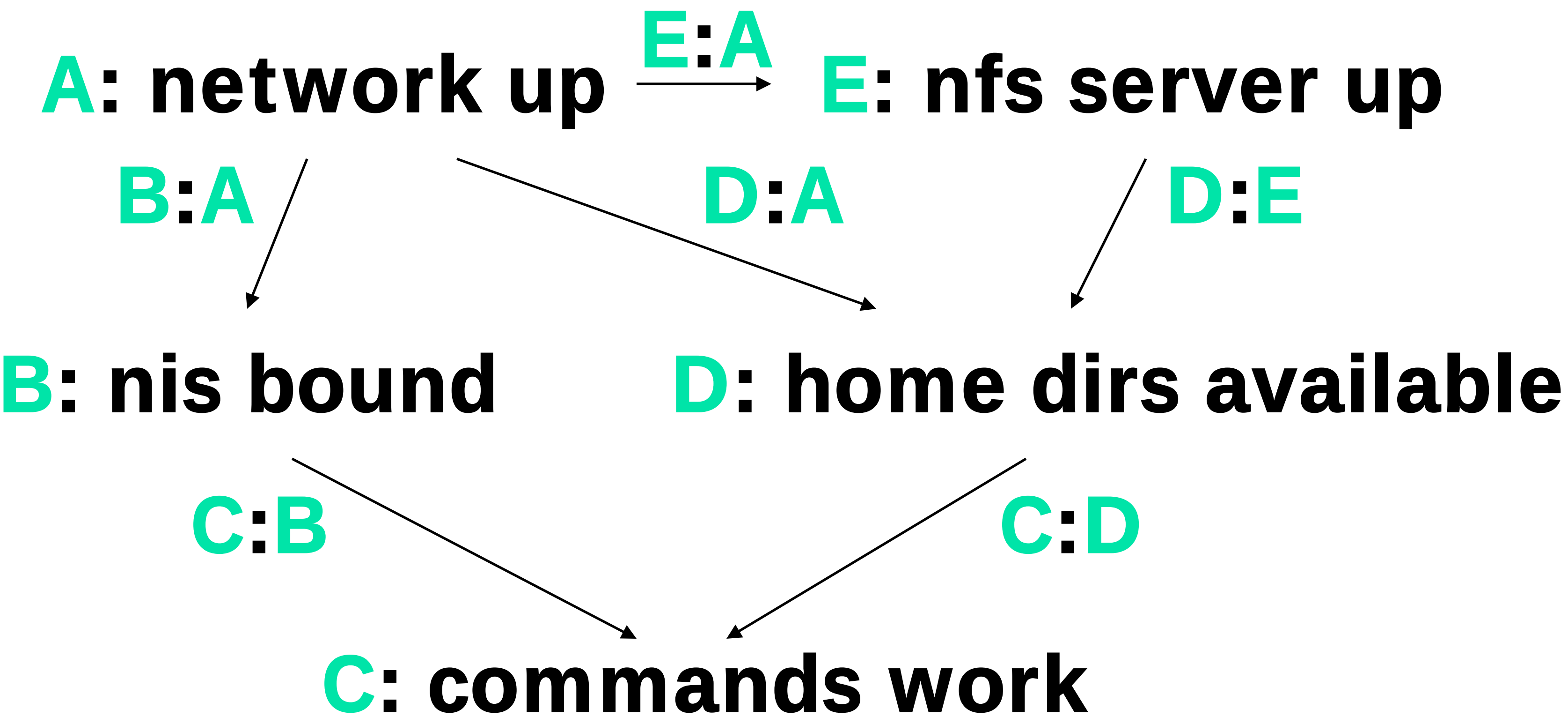
Ideal: “Plug and Play” Automation

- Grab the scripts that you need from others.
- Scripts all just “get along” and work together.
- Make script writers work harder.
- So administrators’ work is easier!

Let’s Automate!

- Suppose we write scripts **A**,**B**,**C**,**D**,**E** to check and repair corresponding functions.
- Normally, we’d have to remember to run them in the order “**A B E D C**”.
- We’d usually do that by predeclaring precedences: **B:A** means “**B** must follow **A**”.

Predeclaring Precedences



A: network up

E:A

E: nfs server up

B:A

D:A

D:E

B: nis bound

D: home dirs available

C:B

C:D

C: commands work

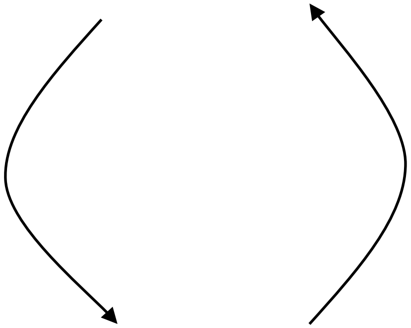
B:A C:B C:D D:A D:E E:A

Predeclaring Precedences Is a Pain!

- Must **know** precedences beforehand.
- Must **update** precedences whenever you add or remove a script.
- In some cases, precedences are **unknown** or **dynamic**!
- In this case, **any fixed order is an ineffective procedure** for troubleshooting some problems.

One Ineffective Procedure

F: filesystem OK



No fixed order
will ensure success.

G: fsck command in filesystem OK

“Chicken and Egg” problem!

Discovering Order

- Suppose that **A**,**B**,**C**,**D**,**E** are crafted so that:
  - They fail robustly when called at the wrong time.
  - They tell you when they fail.
  - They don’t undo each other’s actions.
- Then we may infer their required execution order from their behavior rather than declaring precedences beforehand!

Permutation Embedding

- For a set of objects x1,x2,...,xn, **all permutations** of the objects are **embedded** in the string containing n-1 copies of x1,...,xn, followed by x1.
- E.g., $\underbrace{\underbrace{x1,...,xn},\underbrace{x1,...,xn},......,\underbrace{x1,...xn}}_{\text{n-1 copies}},\underset{\uparrow\ \text{trailing x1}}{x1}$

Example of Permutation Embedding

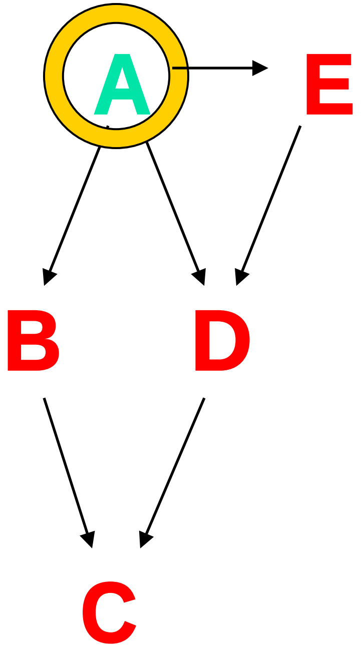
Embedding	Permutation
ABCDEABCDEABCDEABCDEA	ABCDE
ABCDEABCDEABCDEABCDEA	BACDE
ABCDEABCDEABCDEABCDEA	ACBDE
…	…
ABCDEABCDEABCDEABCDEA	ECDBA
ABCDEABCDEABCDEABCDEA	DECBA
ABCDEABCDEABCDEABCDEA	EDCBA

Exploiting Permutation Embedding

- Don’t record precedences.
- Try scripts in embedding sequence.
- Record successes.
- Don’t repeat trials that succeed.
- Retry scripts that fail.
- Until all succeed!

Discovering Order (1)

Precedences



Execution order

A B C D E

A B C D E

A B C D E

A B C D E

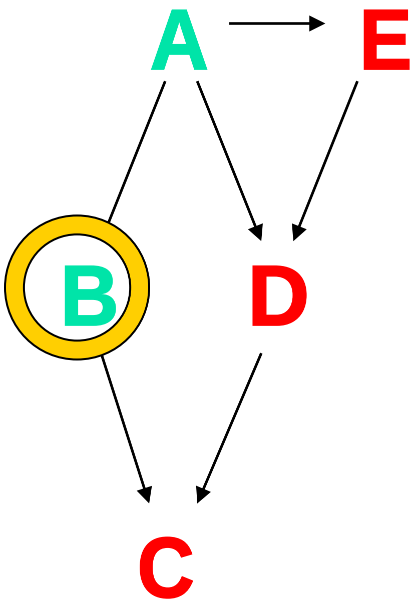
A

Discovered order:

A

Discovering Order (2)

Precedences



Execution order

A B C D E

A B C D E

A B C D E

A B C D E

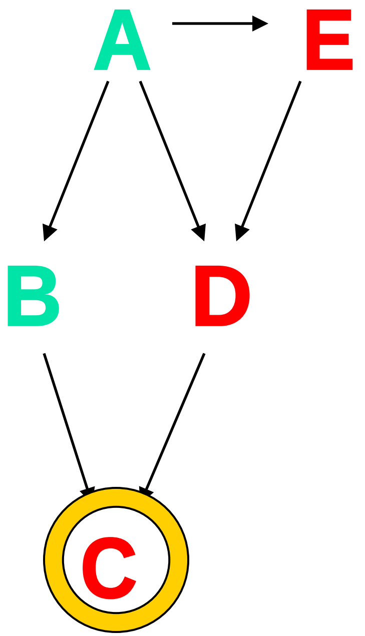
A

Discovered order:

A B

Discovering Order (3)

Precedences



Execution order

A B C D E

A B C D E

A B C D E

A B C D E

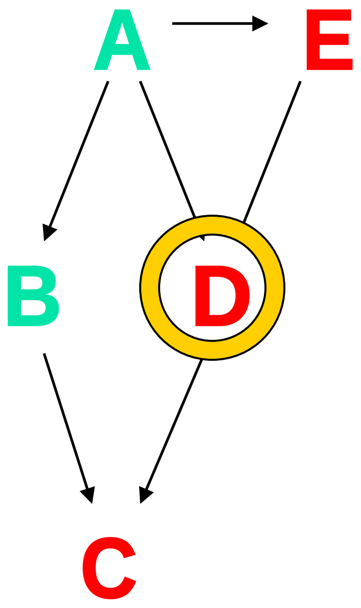
A

Discovered order:

A B

Discovering Order (4)

Precedences



Execution order

A B C D E

A B C D E

A B C D E

A B C D E

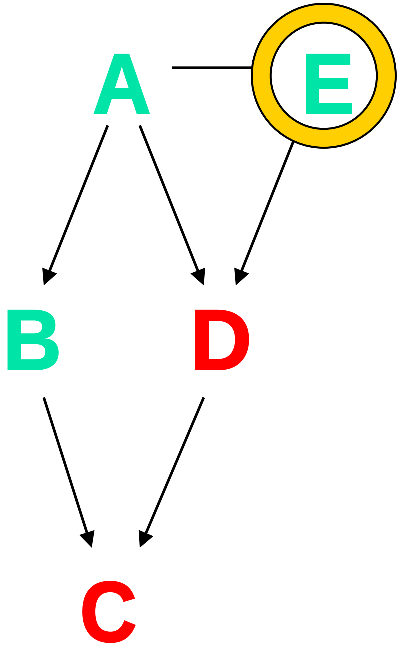
A

Discovered order:

A B

Discovering Order (5)

Precedences



Execution order

A B C D E

A B C D E

A B C D E

A B C D E

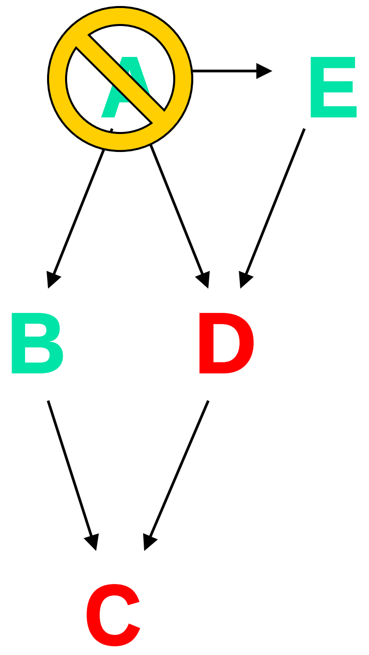
A

Discovered order:

A B E

Discovering Order (6)

Precedences



Execution order

A B C D E

A B C D E

A B C D E

A B C D E

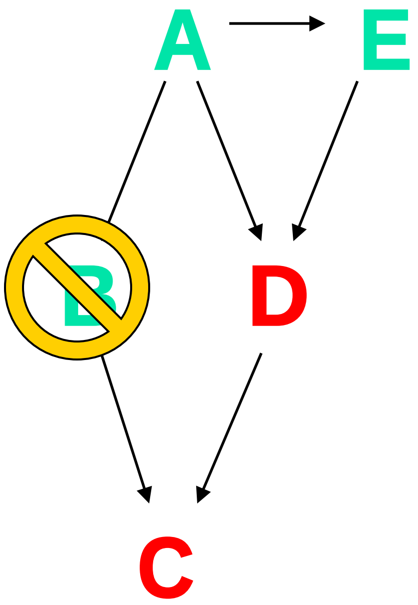
A

Discovered order:

A B E

Discovering Order (7)

Precedences



Execution order

A B C D E

A B C D E

A B C D E

A B C D E

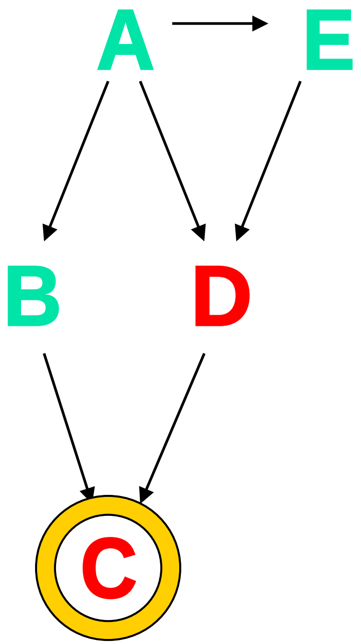
A

Discovered order:

A B E

Discovering Order (8)

Precedences



Execution order

A B C D E

A B C D E

A B C D E

A B C D E

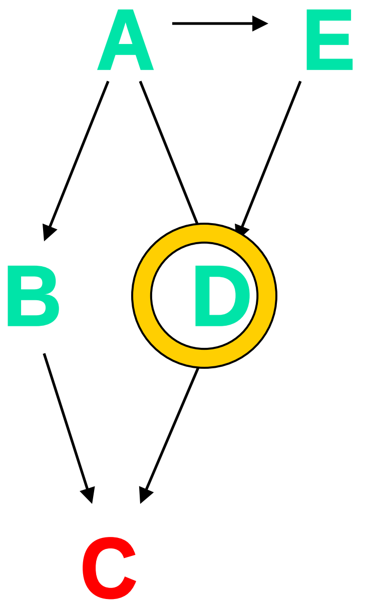
A

Discovered order:

A B E

Discovering Order (9)

Precedences



Execution order

A B C D E

A B C D E

A B C D E

A B C D E

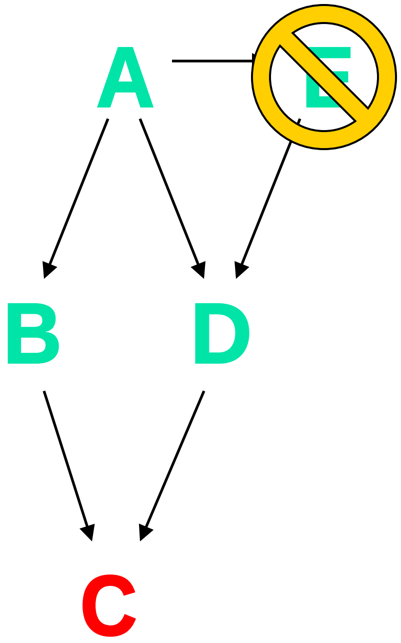
A

Discovered order:

A B E D

Discovering Order (10)

Precedences



Execution order

A B C D E

A B C D E

A B C D E

A B C D E

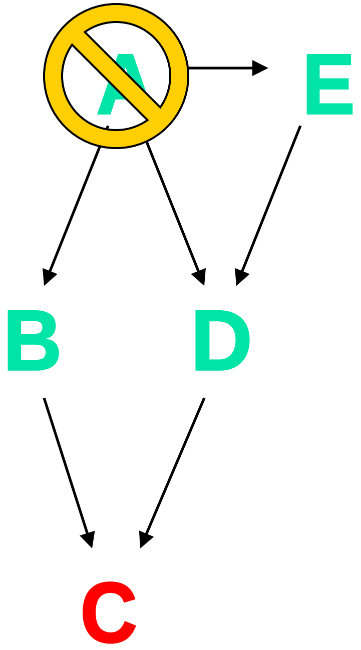
A

Discovered order:

A B E D

Discovering Order (11)

Precedences



Execution order

A B C D E

A B C D E

A B C D E

A B C D E

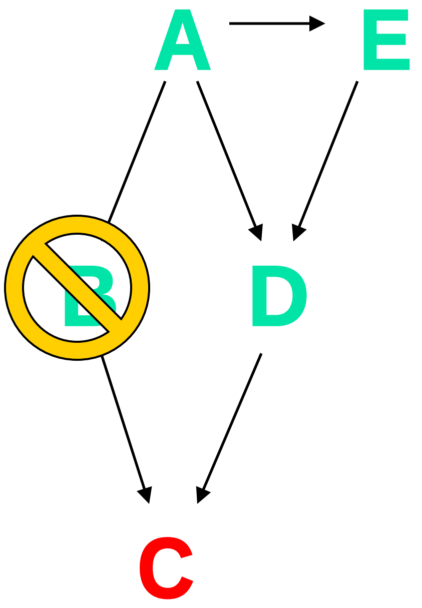
A

Discovered order:

A B E D

Discovering Order (12)

Precedences



Execution order

A B C D E

A B C D E

A B C D E

A B C D E

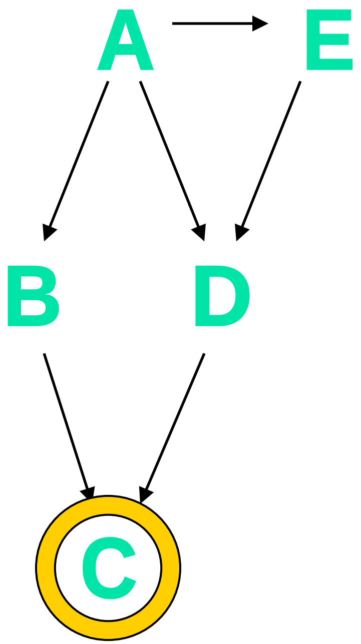
A

Discovered order:

A B E D

Discovering Order (13)

Precedences



Execution order

A B C D E

A B C D E

A B C D E

A B C D E

A

Discovered order:

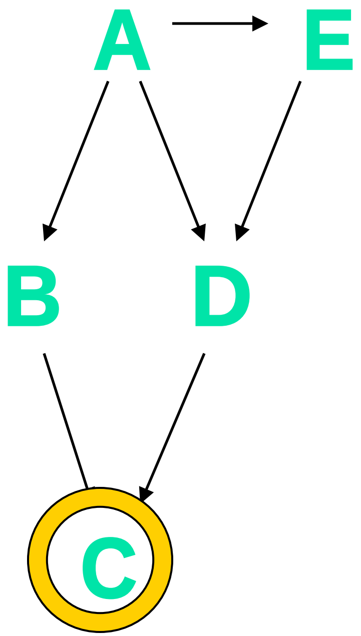
A B E D C

Effect of Initial Ordering

- Efficiency depends upon **initial ordering** of tasks.
- **Best case**: initial order is **appropriate order.**
- **Worst case**: initial order is **opposite to appropriate order.**

Best Case: ABEDC

Precedences



Execution order

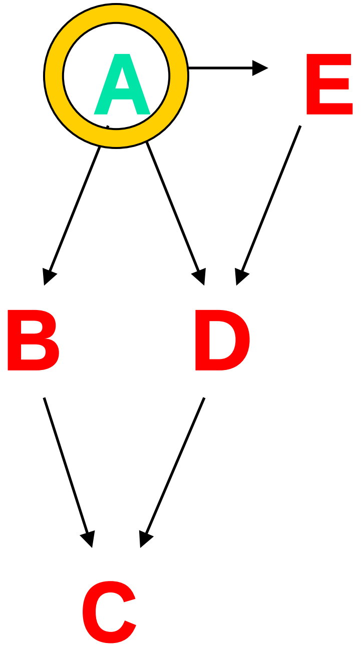
A B E D C
A B E D C
A B E D C
A B E D C
A

Discovered order:

A B E D C

Worst Case: CBDEA (1)

Precedences



Execution order

C B D E A

C B D E A

C B D E A

C B D E A

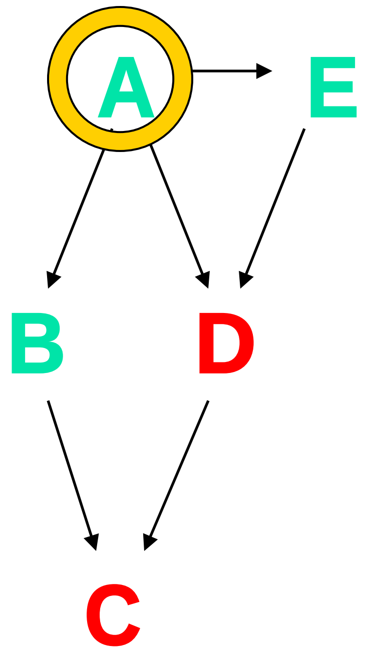
C

Discovered order:

A

Worst Case: CBDEA (2)

Precedences



Execution order

C B D E A

C B D E A

C B D E A

C B D E A

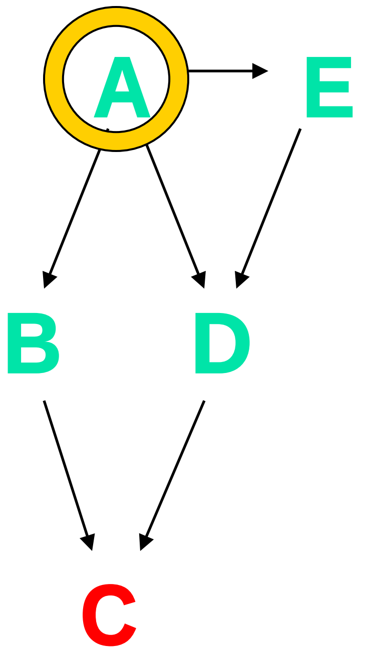
C

Discovered order:

A B E

Worst Case: CBDEA (3)

Precedences



Execution order

C B D E A

C B D E A

C B D E A

C B D E A

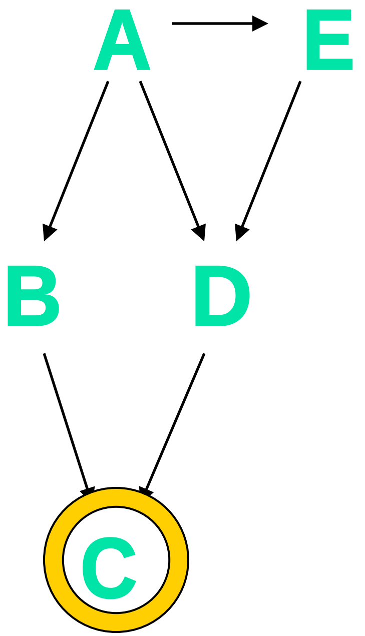
C

Discovered order:

A B E D

Worst Case: CBDEA (4)

Precedences



Execution order

C B D E A

C B D E A

C B D E A

C B D E A

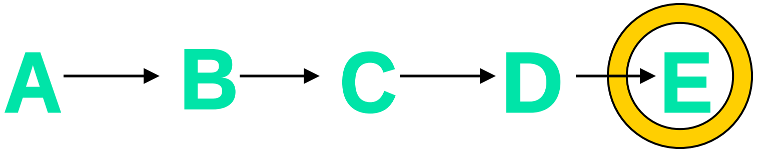
C

Discovered order:

A B E D C

How Bad Can Bad Get?

Precedences



Execution order

E D C B A

E D C B A

E D C B A

E D C B A

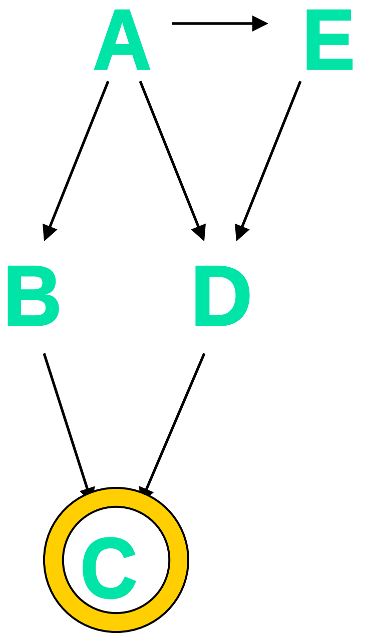
E

Discovered order:

A B C D E

Small Errors Mean Small Inefficiencies

Precedences



Execution order

A B D ↔ E C

A B D E C

A B D E C

A B D E C

A

Discovered order:

A B E D C

Implementation: The Maelstrom

- The **mael** command is a dispatcher for a set of scripts.
- Input is a list of commands to try.
- **Mael** tries to make them all **succeed** (exit code 0).
- Nonzero exit code means **failure**; try again.

Seeding the Storm

- Can give **mael** hints and other information about its commands.
- **B:A** - **I think** command **B** should be tried after **A**.
- **B::A** – **B cleans up after A**. **B** must be retried if it succeeds before **A**.
- **B:::A – I know B** will only succeed after **A**.

Command Requirements

- Maelstrom only functions correctly if the commands that it dispatches are:
- **Aware**: commands know whether they failed.
- **Homogeneous**: commands that change the same system attribute change it in the same way.
- (**Convergent**: commands that discover that goals are already met do nothing.)

How Difficult Is It to Write a Conforming Maelstrom Script?

- Easy part: **awareness.**
  - **Local** to the script.
  - Insert enough branches to check for script preconditions.
- Hard part: **homogeneity.**
  - **Global** convergence criterion.
  - All scripts must agree on desired effects.

Form of Maelstrom Script

- **Check all preconditions** necessary for script function.
- If preconditions are not present, **fail**.
- Else try to **fix a problem**.
- If that seems to work, **succeed**.
- Else **fail**.

Engineering Maelstrom Scripts

- No preconditions for the script as a software unit.
- Safe to run in any sequence with other scripts.
- Only thing in doubt: **homogeneity**.
- Do scripts agree on what to do?

Imperfect Storms

- **::**, **:::** help compensate for imperfect command behavior.
- **A::B** – **A** and **B** aren't **homogeneous** and **A** should be done **last**, even if **B** succeeded last.
- **A:::B –** **A** isn't **aware** that it needs **B**, so do **B** **first**.

A Lesson Learned

- **Causality** is a **myth** in a sufficiently complex system.
- Cannot determine what will happen **in general**.
- Can determine what **repaired a specific problem**.
- This is not the same as what **caused the problem**.

Not Causal, but Operational

- **Impossible** to determine **true precedences** between tasks by direct observation (Sandnes).
- **Easy** to determine **an order that satisfies unknown precedences.**

But Wait, There’s More! In the Paper:

- **Decision trees** represent best practices.
- **Mael**’s commands can represent decision trees.
- **Mael** replaces **make**’s global precedence knowledge with dynamic probes during commands.
- Can implement **make** in **mael**.

Status and Availability

- http://www.eecs.tufts.edu/~couch/maelstrom
- Platform: Perl 5.
- Portable to most any system.
- Intensively tested on a “precedence simulator” that simulates behavior of troubleshooting scripts.
- Working on script content now.