Towards Automatically Checking Thousands of Failures with Micro-Specifications

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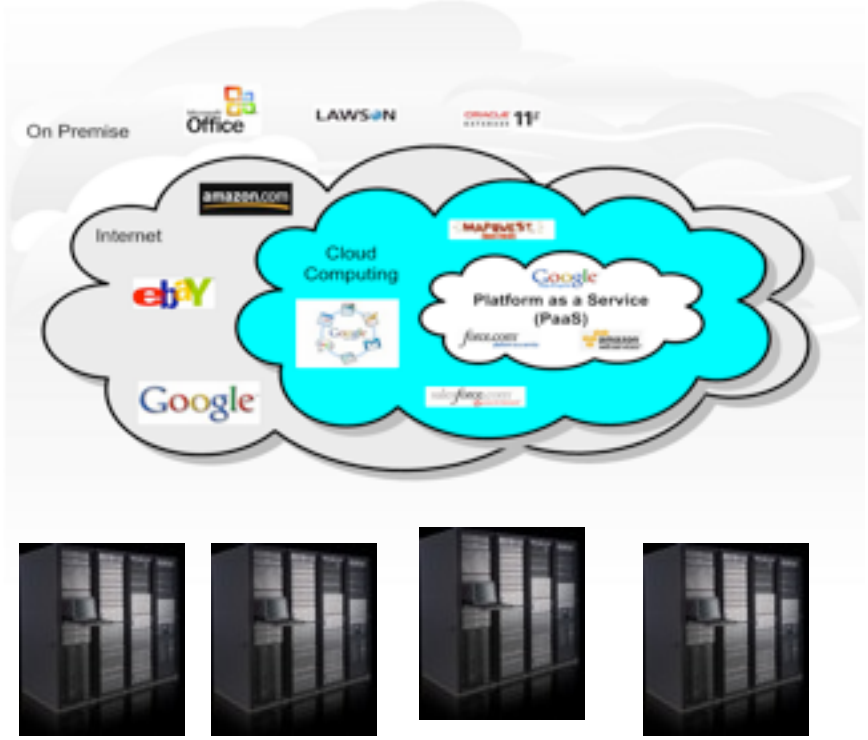
Cloud Era

Solve bigger human problems

Use cluster of thousands of machines



Failures in The Cloud

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3

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"Recovery must be a **first-class** operation" – **Raghu Ramakrishnan**

"Reliability has to **come from the software**" – **Jeffrey Dean**

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PRO RESEARCH EVENTS

HOME APPLE CLEANTECH CLOUD COLLABORATION MOBILE VIDEO

Paisano: Ashton Kutcher Has Little Twitter Influence [STUDY] http://bit.ly/bx8uM4

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When the Cloud Fails: T-Mobile, Microsoft Lose Sidekick Customer Data

By Om Malik | Oct. 10, 2009, 3:57pm PDT | 32 Comments

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If you've ever been curious about what would happen when a cloud service fails, then you don't have to wonder any longer. Earlier today, customers of T-Mobile and Sidekick data services provider Danger, a subsidiary of Microsoft, lost access to all their data. Some believe that this data wipeout is because of a botched upgrade. Why it happened matters little to those who are unlikely to get their data back, according to a note posted on T-Mobile forums.

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News

Facebook temporarily loses more than 10% of photos in hard drive failure

Facebook is working to restore access to the photos

By Lucas Mearian
March 9, 2009 12:00 PM ET

Comments (5) Recommended (33) Share

Computerworld - Popular social networking site Facebook.com admitted in a blog post today that over the weekend, a hard drive failure led to the temporary loss of 10% to 15% of the photographs stored by its users.

According to the company, several drives failed at once during a routine upgrade Friday night.

"You may have noticed in the past day that some photos aren't appearing or are displaying a 'question mark' graphic when you go to view them. We're trying to fully understand what happened, since simultaneous hardware failures like this are rare," Evan Priestley, an engineer at Facebook

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Why Failure Recovery Hard?

- Testing is not advanced enough against complex failures
  - Diverse, frequent, and multiple failures
  - FaceBook photo loss
- Recovery is under specified
  - Need to specify failure recovery behaviors
  - Customized well-grounded protocols
- Example: Paxos made live – An engineering perspective [PODC' 07]

Our Solutions

7

Our Solutions

- **FTS ("FATE")** – Failure Testing Service
  - New abstraction for failure exploration
  - Systematically exercise **40,000** unique combinations of failures

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- **DTS ("DESTINI")** – Declarative Testing Specification
  - Enable concise recovery specifications
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- Note: Names have changed since the paper

7

Summary of Findings

- Applied FATE and DESTINI to three cloud systems: HDFS, ZooKeeper, Cassandra
- Found 16 new bugs
- Reproduced 74 bugs
- Problems found
  - Inconsistency
  - Data loss
  - Rack awareness broken
  - Unavailability

8

Outline

- ✓ Introduction
- FATE
- DESTINI
- Evaluation
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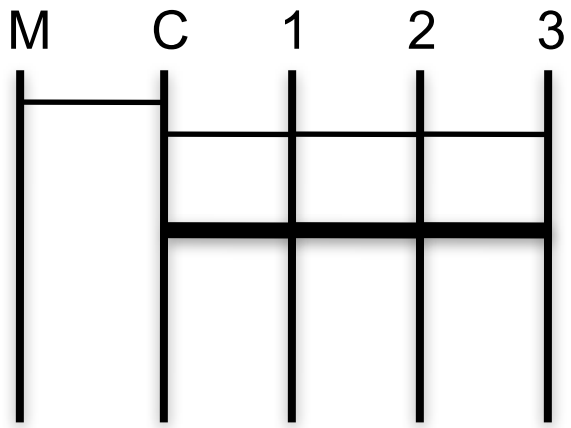
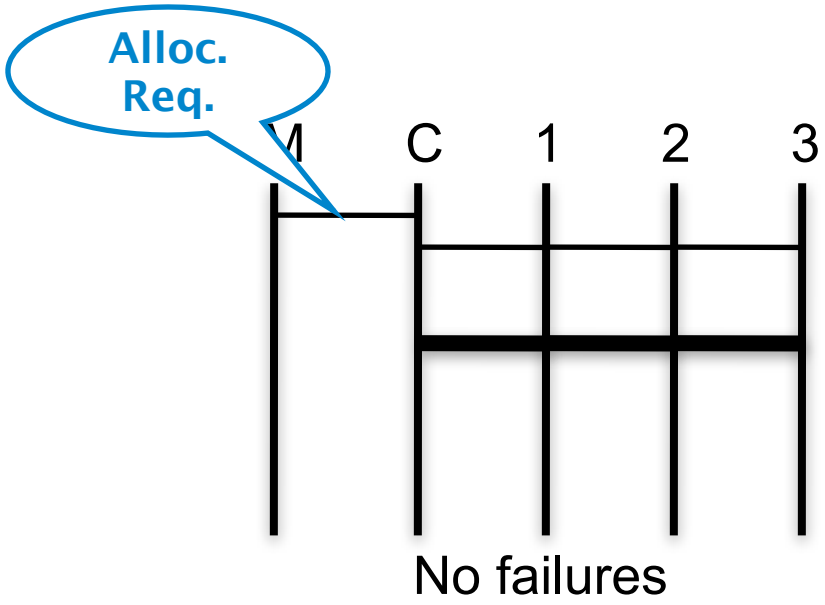
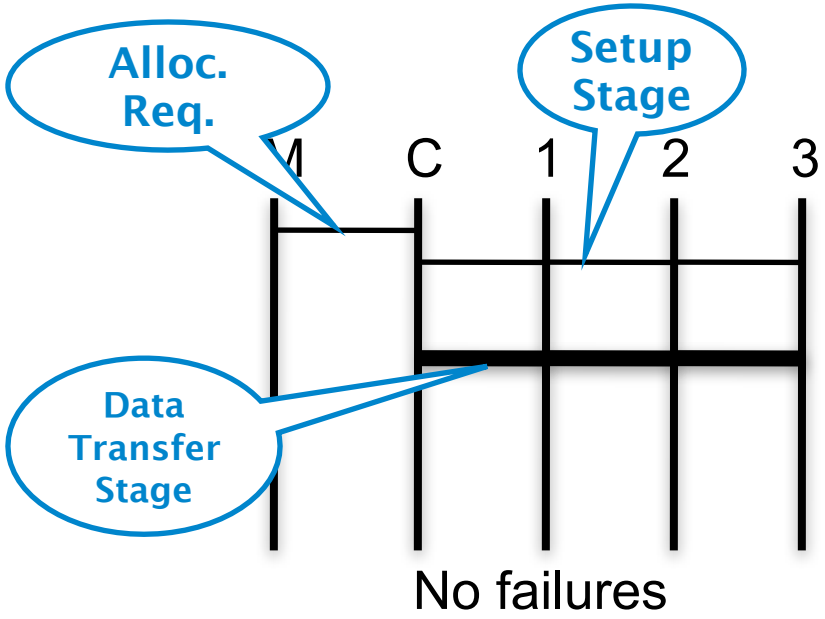
9

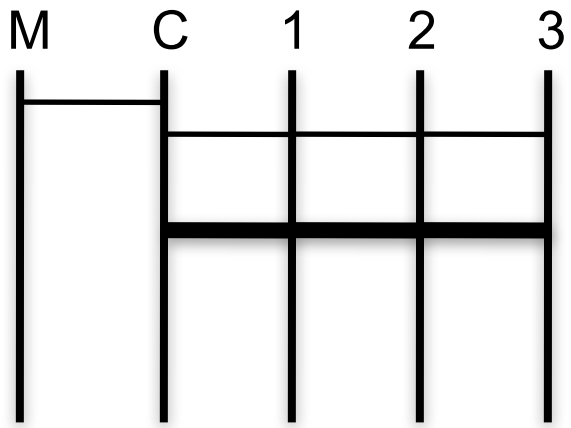


No failures


Alloc.
Req.
M
C
1
2
3
No failures


Alloc.
Req.
Setup
Stage
M
C
1
2
3
Data
Transfer
Stage
No failures

10



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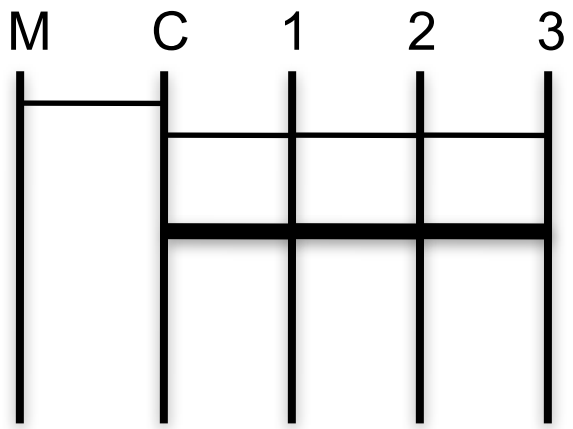

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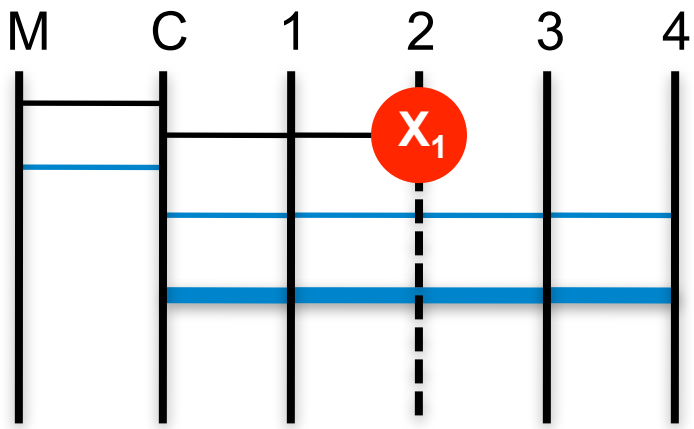
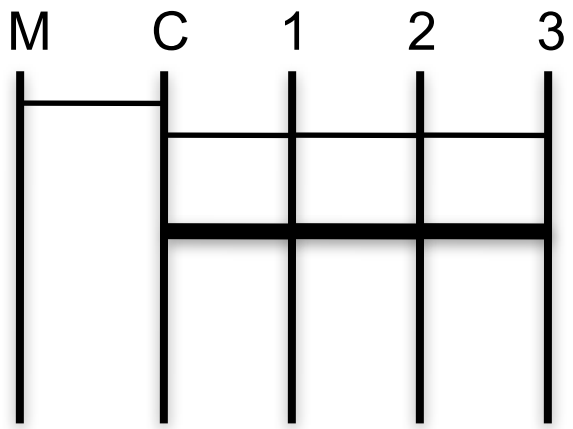


Setup Stage Recovery:
Recreate fresh pipeline



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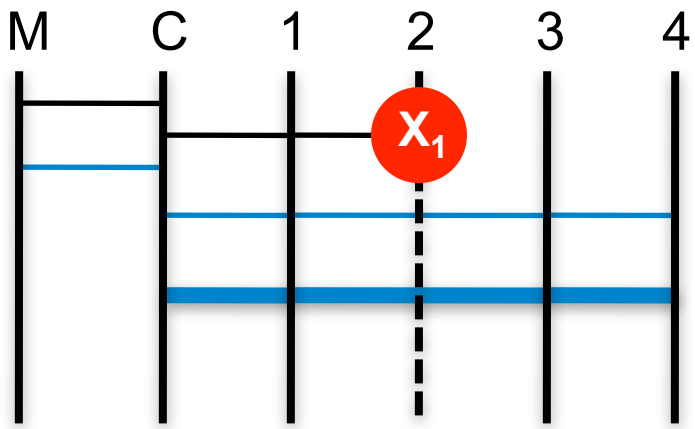

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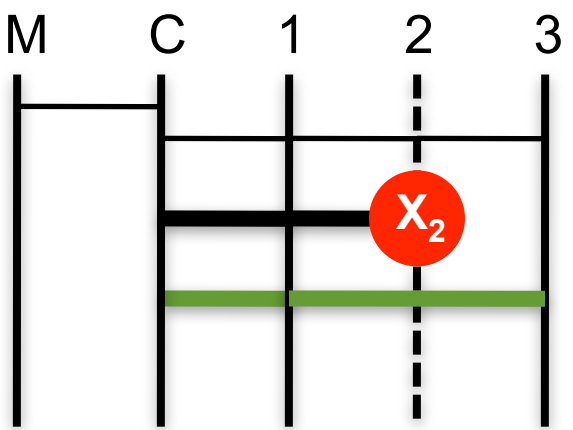
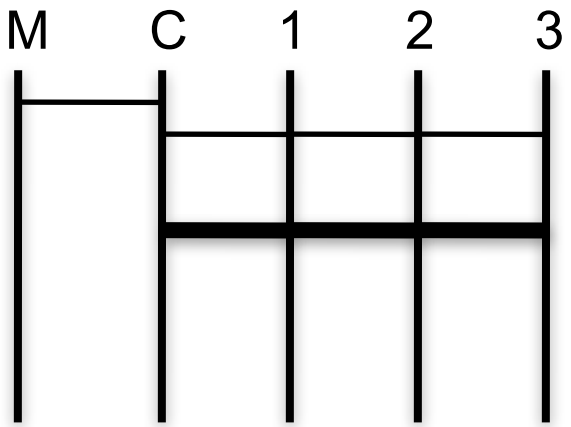


Data transfer Stage Recovery:
Continue on surviving nodes



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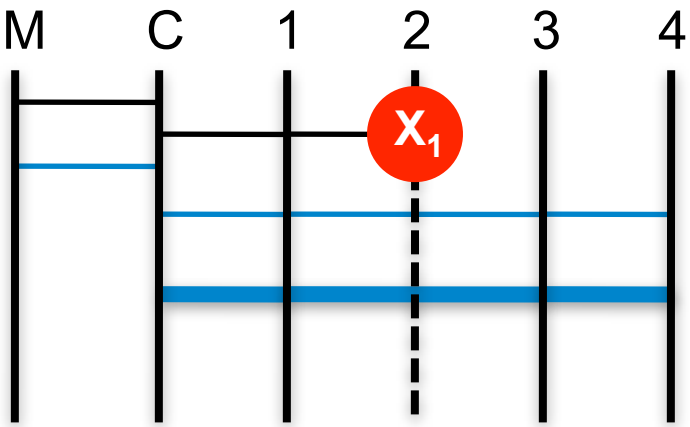

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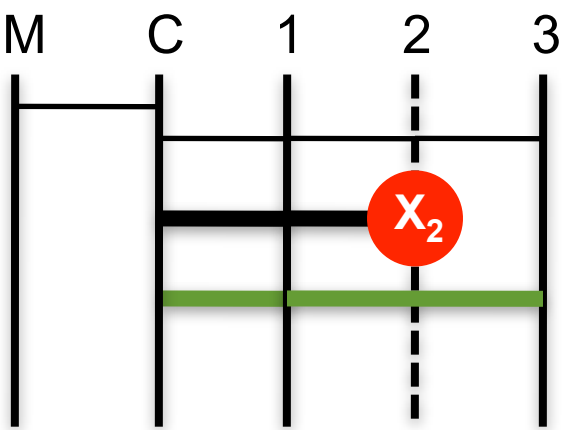

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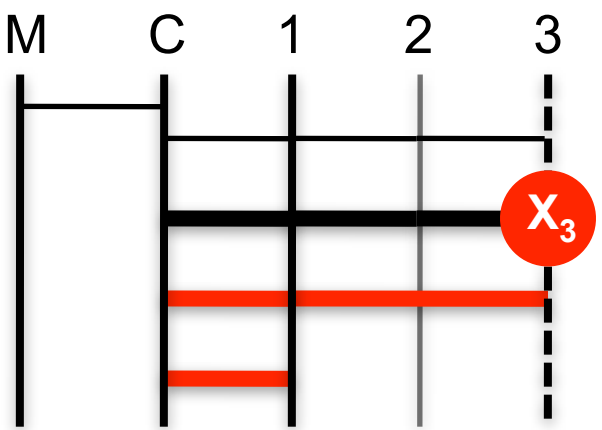

Bug in Data Transfer Stage Recovery

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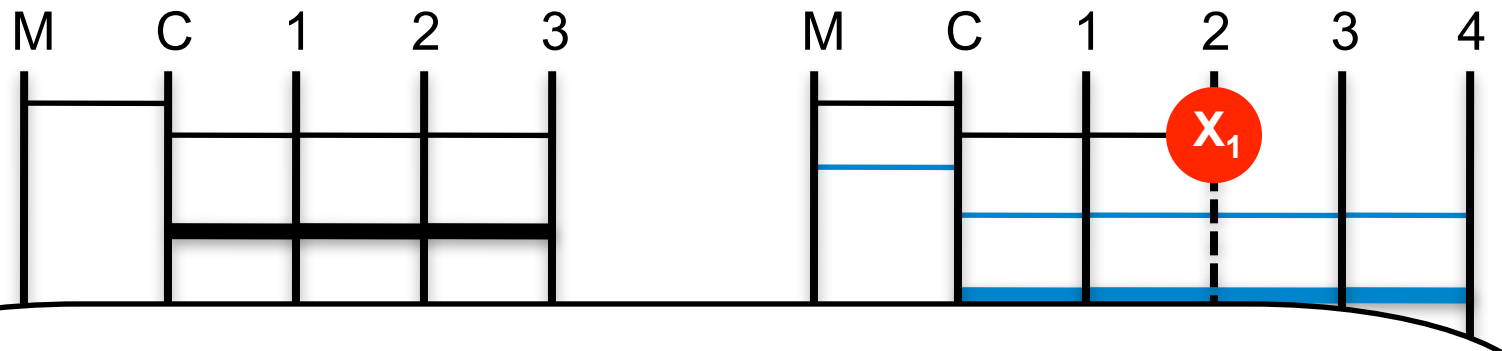

Failures at
DIFFERENT STAGES
lead to
DIFFERENT FAILURE BEHAVIORS

Goal: Exercise different failure recovery path

Data transfer Stage Recovery: Continue on surviving nodes

Bug in Data Transfer Stage Recovery

FATE

- A failure injection framework
  - target IO points
  - Systematically exploring failure
  - Multiple failures
- New abstraction of failure scenario
  - Remember injected failures
  - Increase failure coverage

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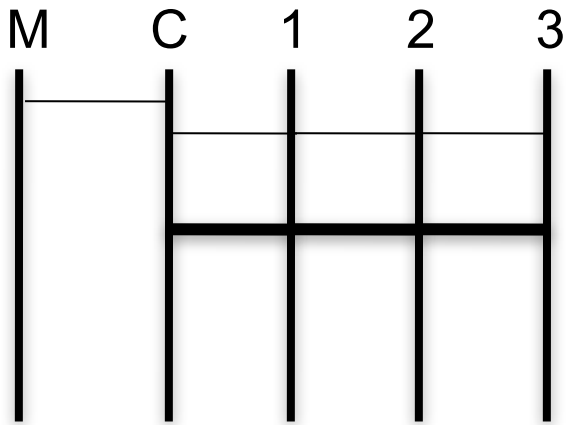

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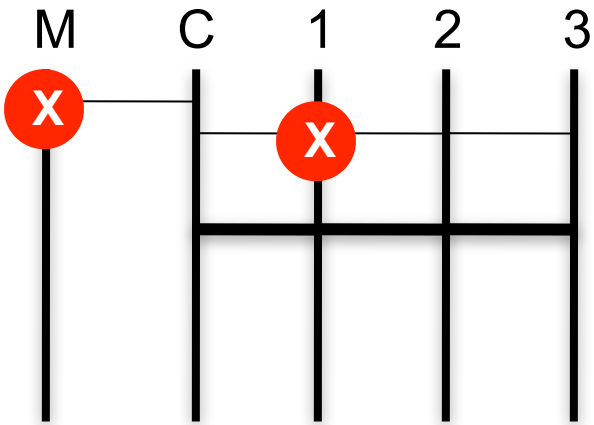

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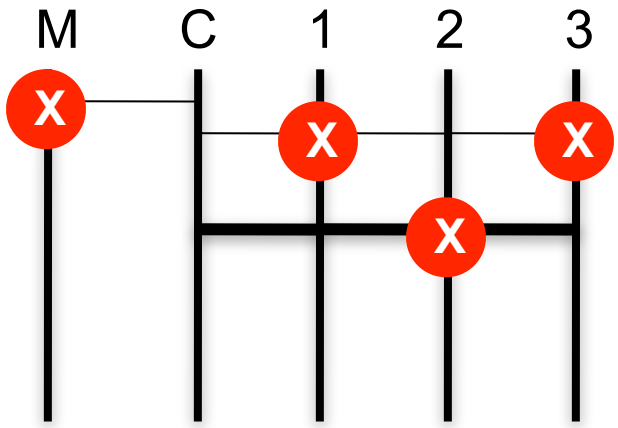

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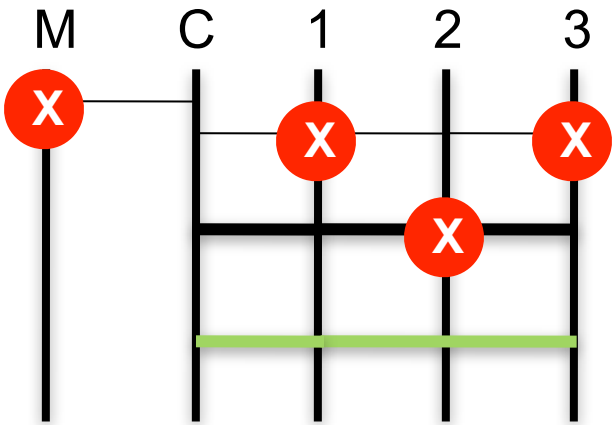

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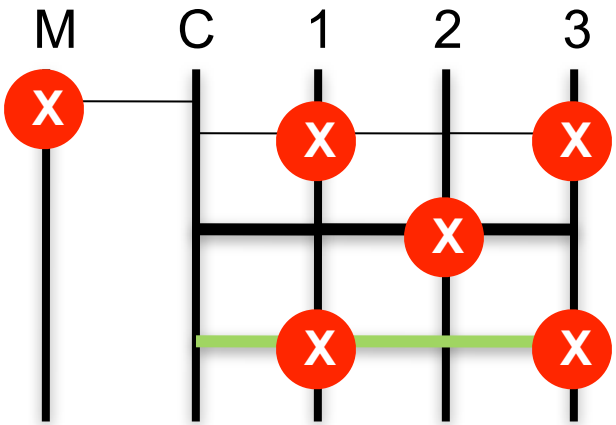

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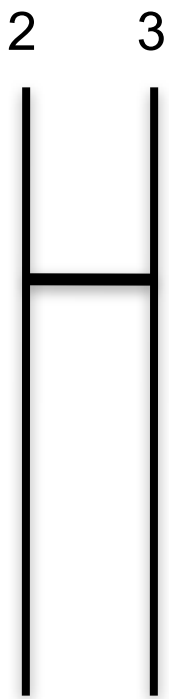
Failure ID



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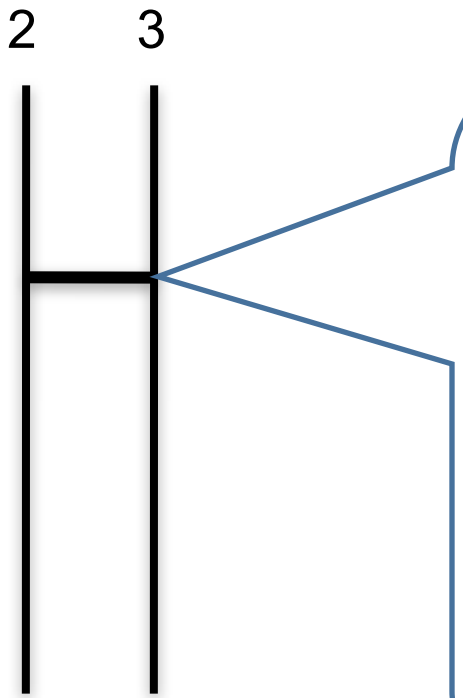


Fields		Values
Static	Func. Call	OutputStream.read()
	Source File	BlockReceiver.java
Dynamic	Stack Track	…
Domain specific	Source	Node 2
	Destination	Node 3
	Net. Message	Data Packet
Failure	Type	Crash After
Hash	**12348729**	

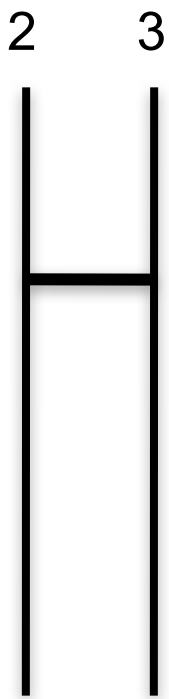
12

How Developers Build Failure ID?

- FATE intercepts all I/Os
- Use aspectJ to collect information at every I/O point
  - I/O buffers (e.g file buffer, network buffer)
  - Target I/O (e.g. file name, IP address)
- Reverse engineer for domain specific information

13

Failure ID



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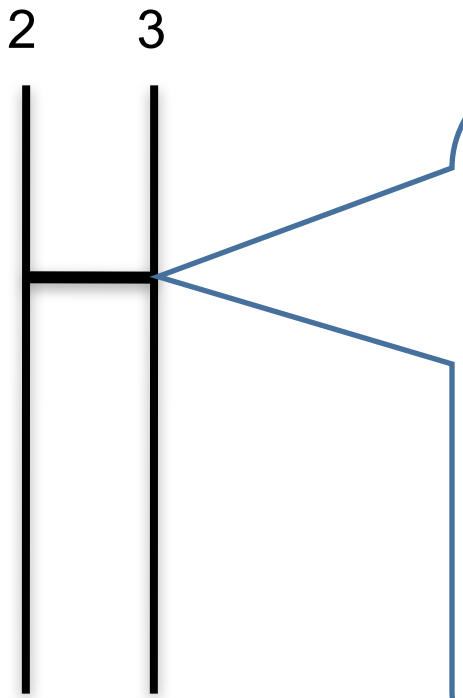

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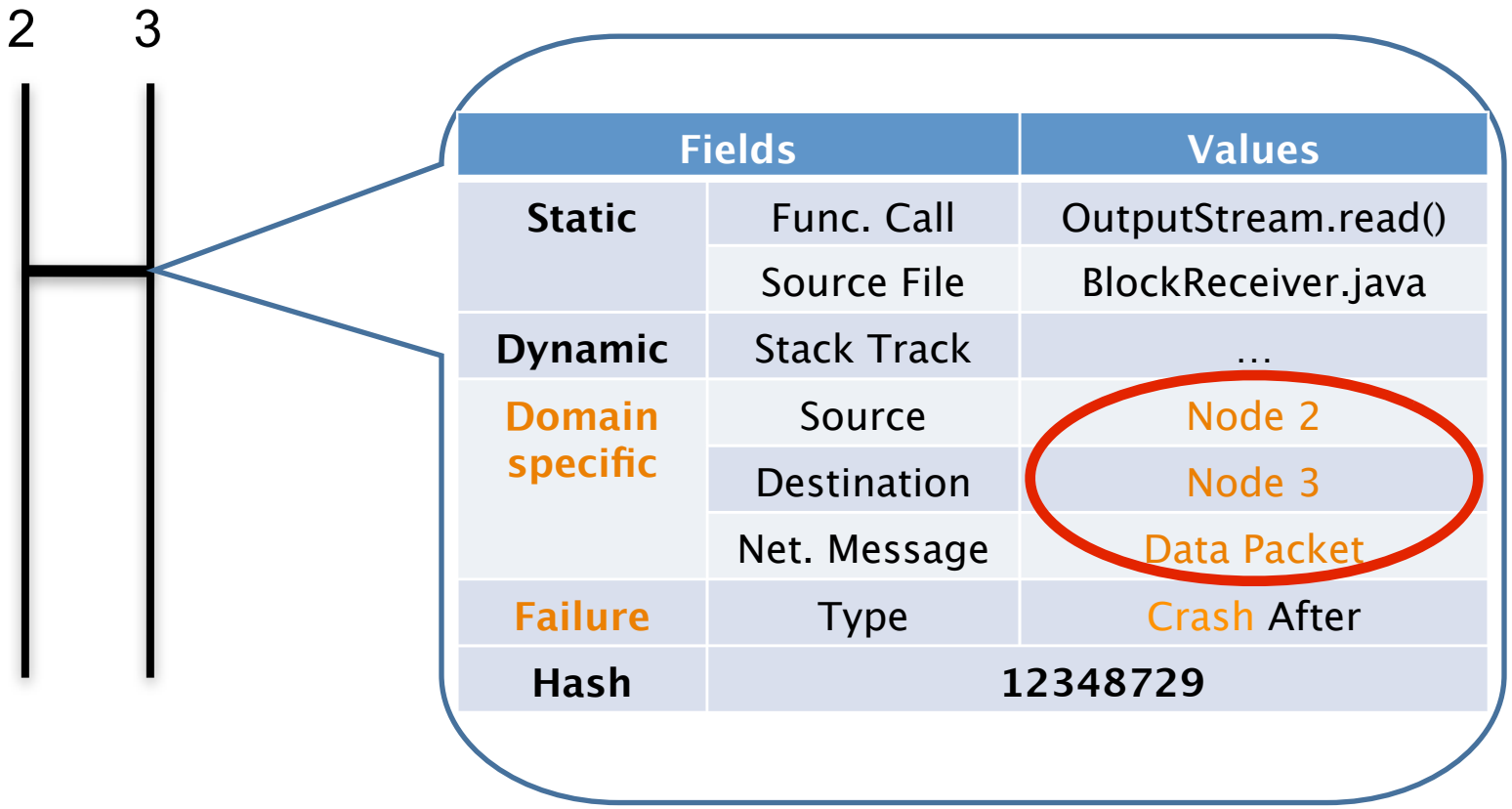
2
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Exploring Failure Space

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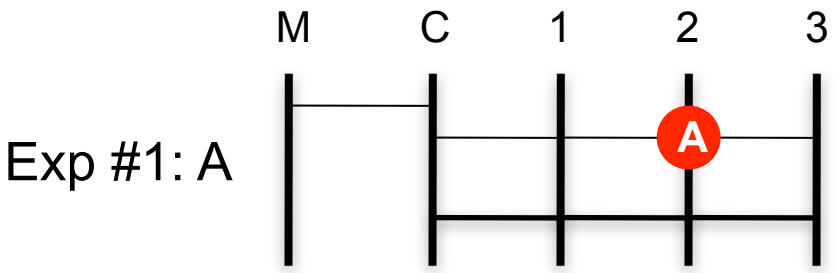

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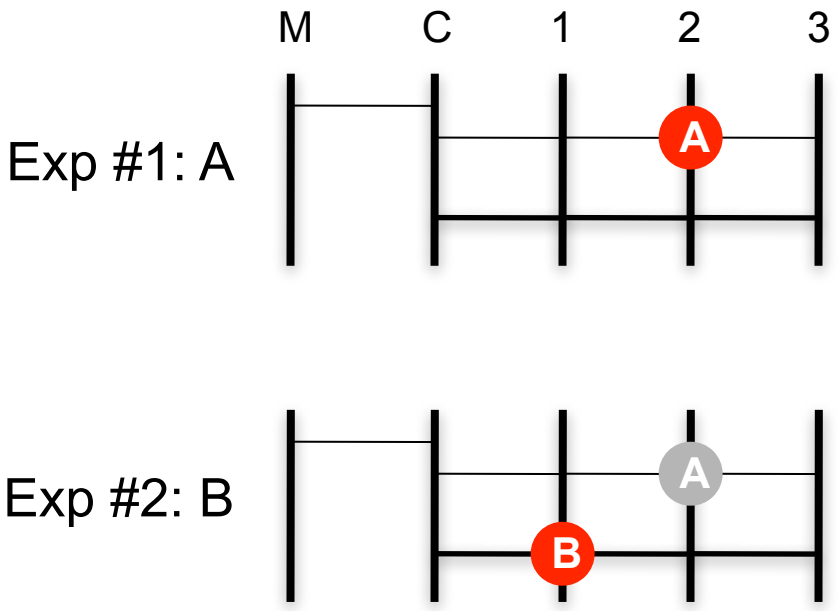

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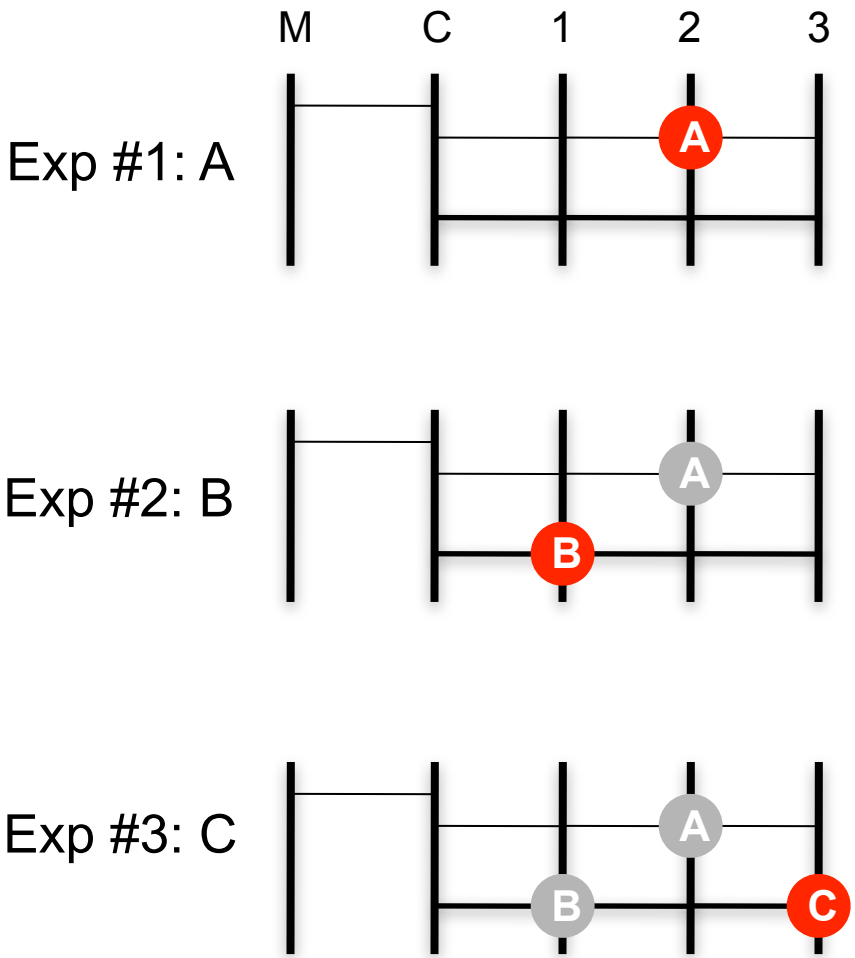

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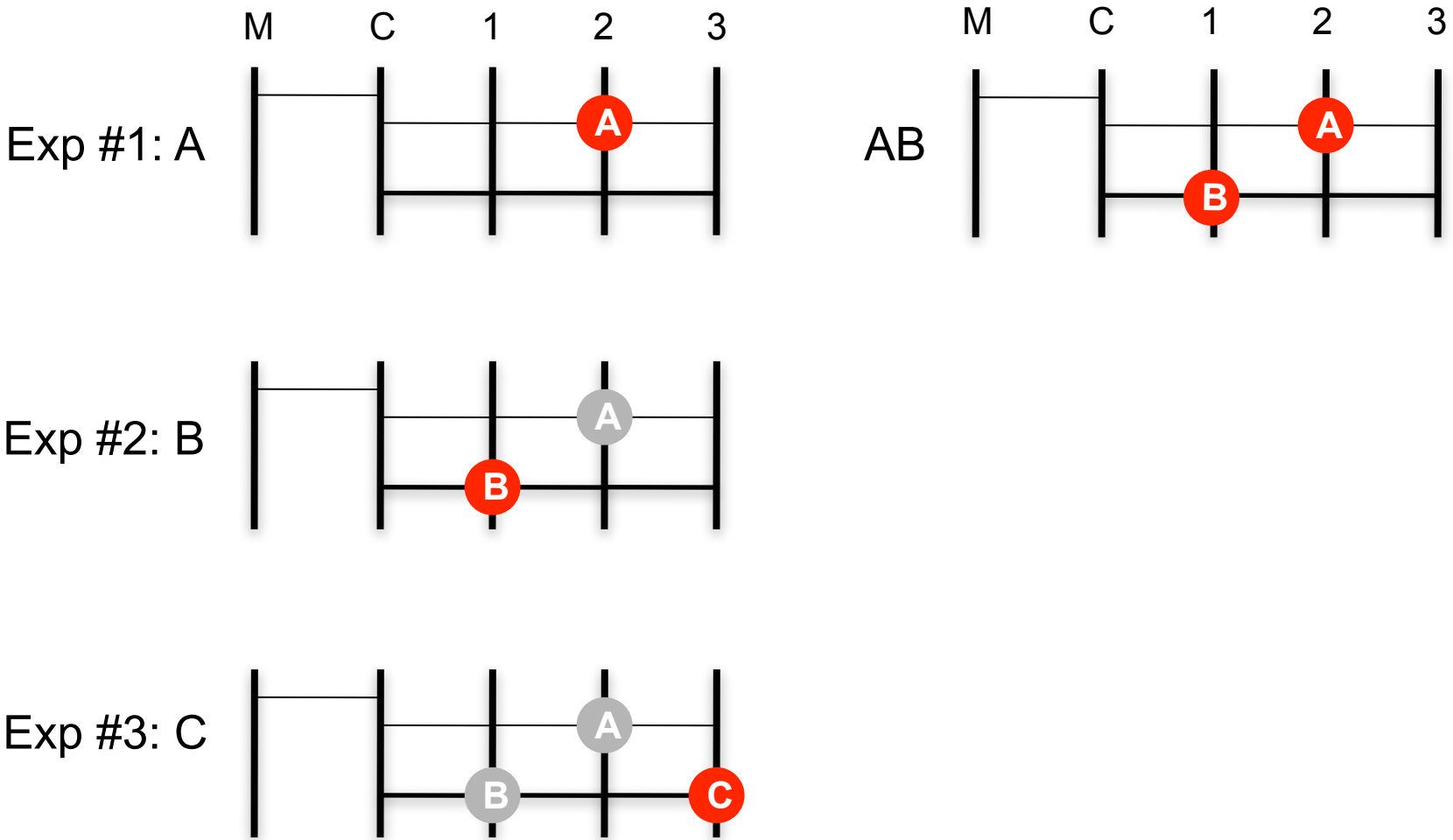

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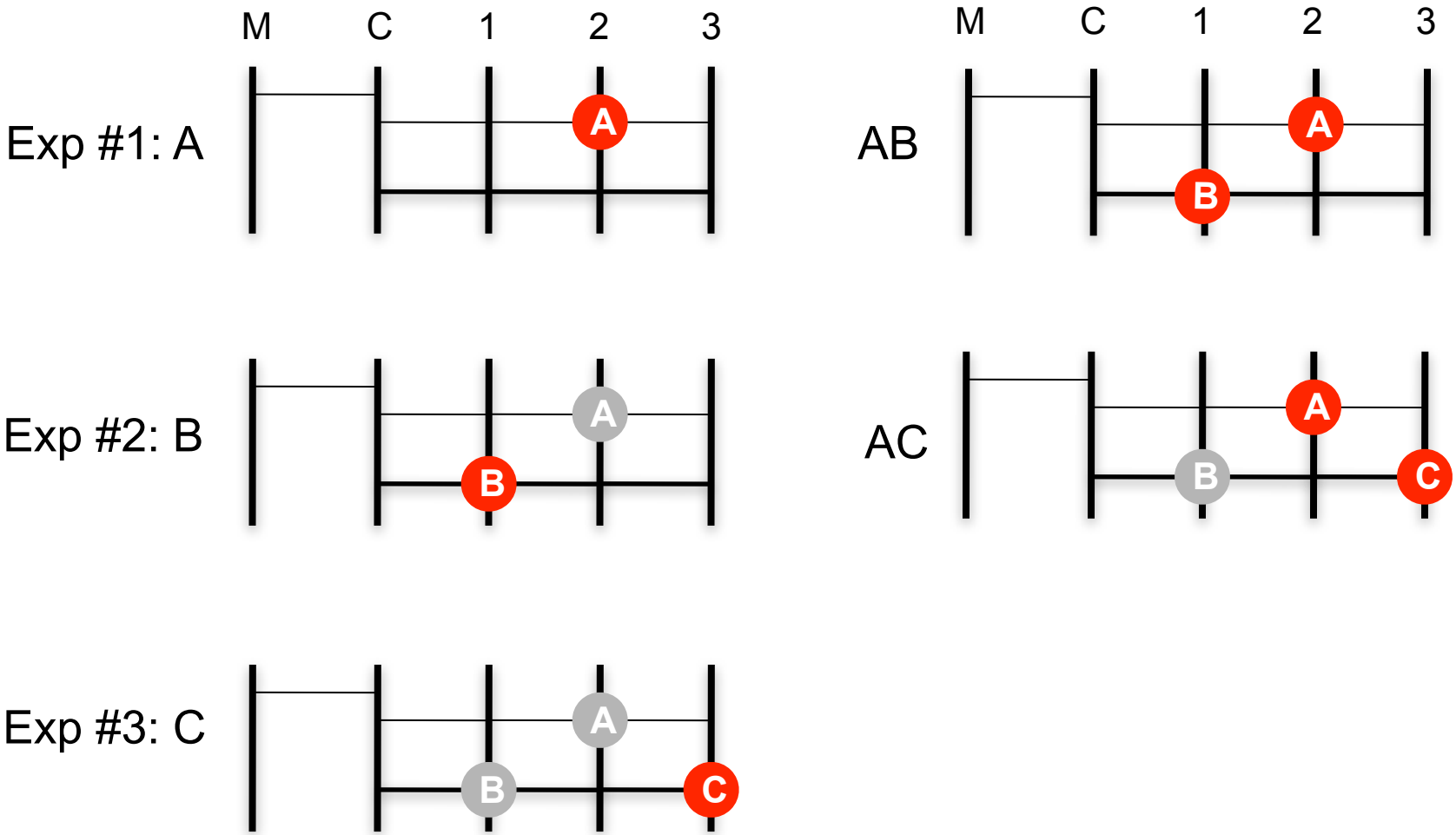

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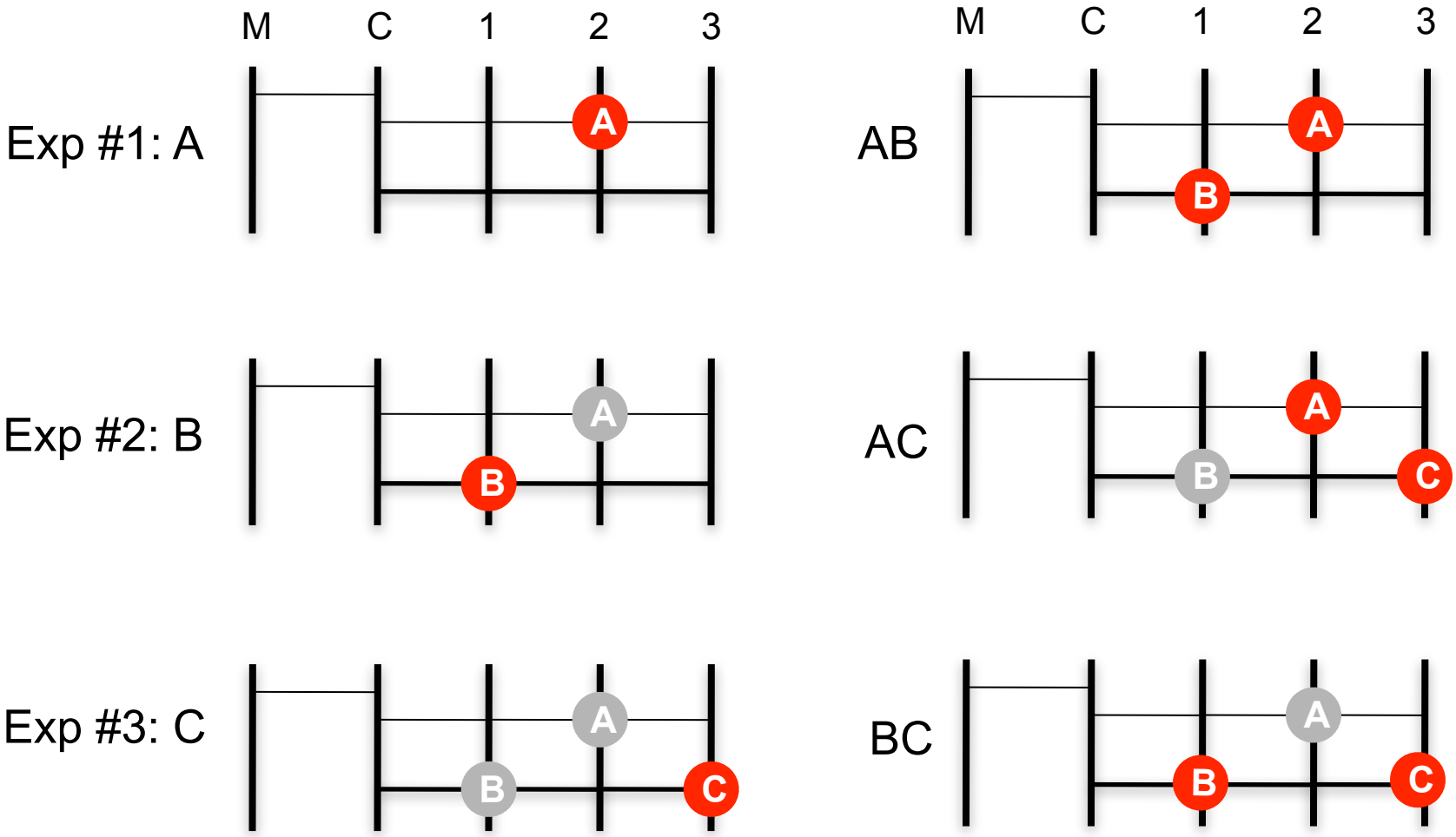

Outline

- ✓ Introduction
- ✓ FATE
- DESTINI
- Evaluation
- Summary

DESTINI

- Enable concise recovery specifications
- Check if expected behaviors match with **actual** behaviors
- Important elements:
  - Expectations
  - **Facts**
  - Failure Events
  - Check Timing
- Interpose network and disk protocols

Writing specifications

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"Violation if expectation is different from actual facts"

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violationTable():- expectationTable(), **NOT-IN** actualTable()

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DataLog syntax:

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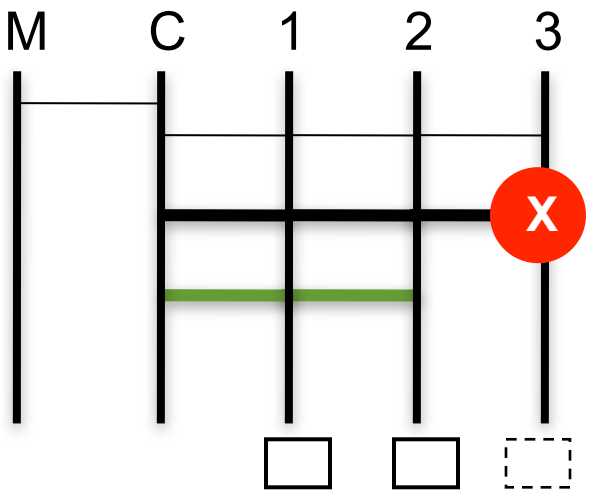
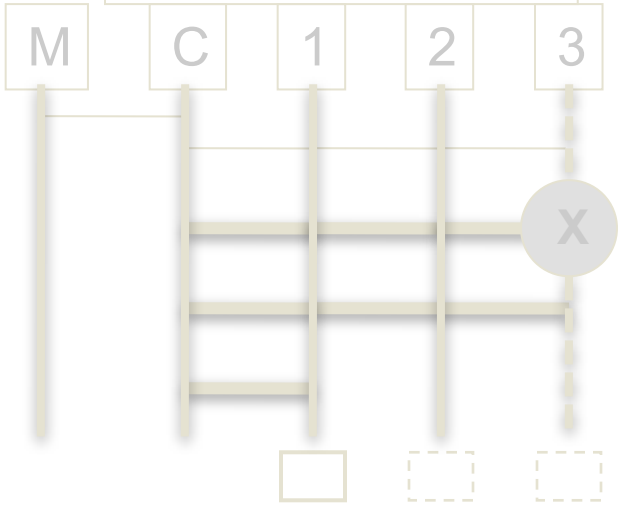
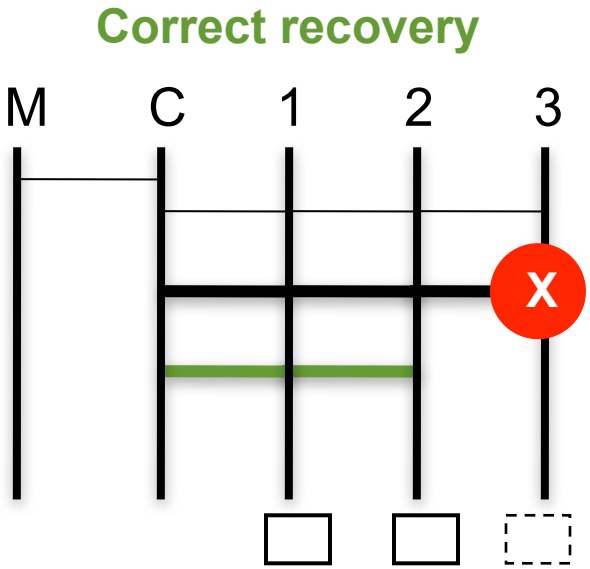
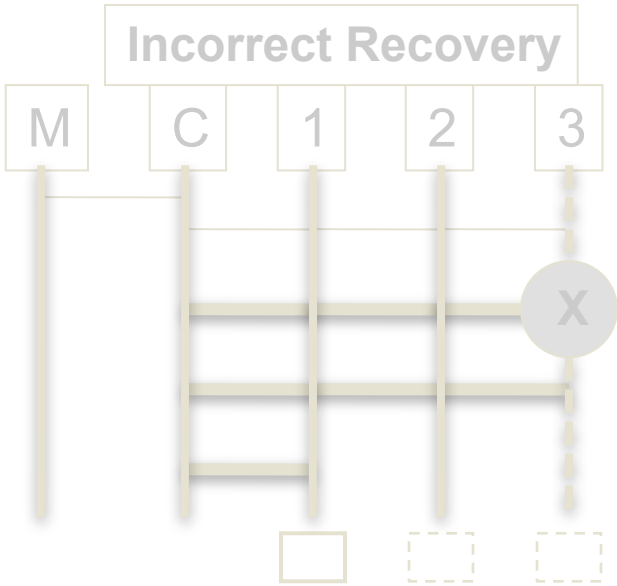
Correct recovery



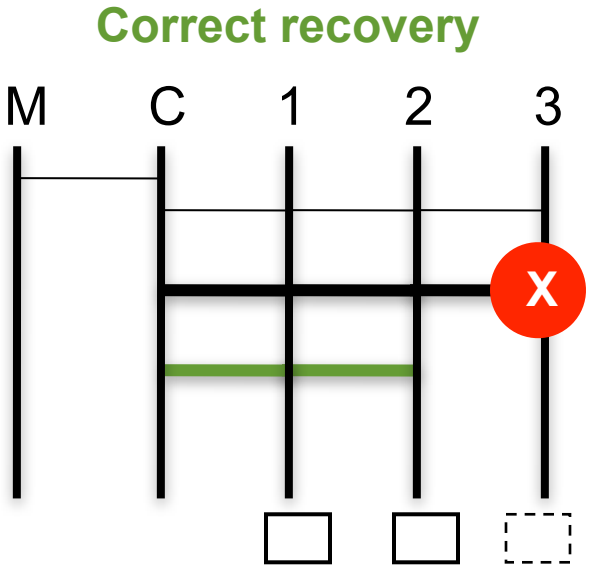
Incorrect Recovery

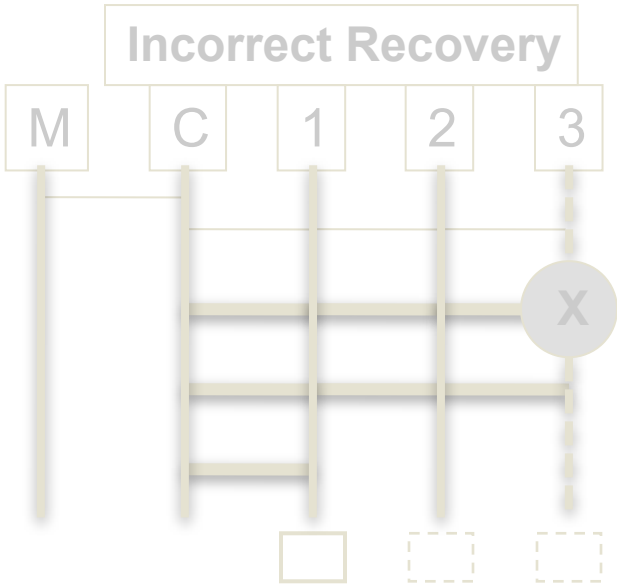






incorrectNodes(B, N) :- **expectedNodes**(B, N), NOT-IN **actualNodes**(B, N);





Expected Nodes (Block, Node)	
B	Node 1
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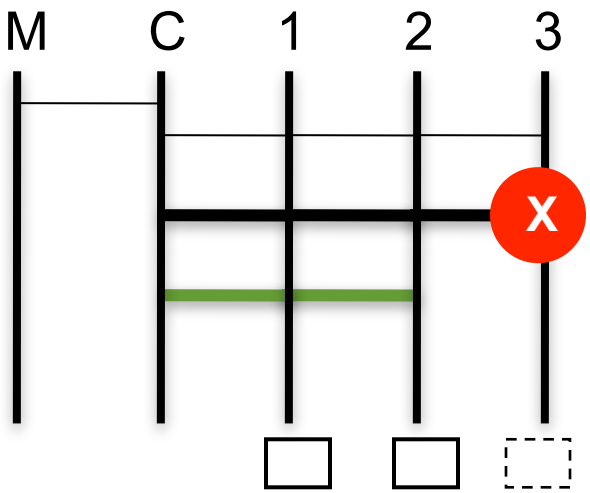
Correct recovery



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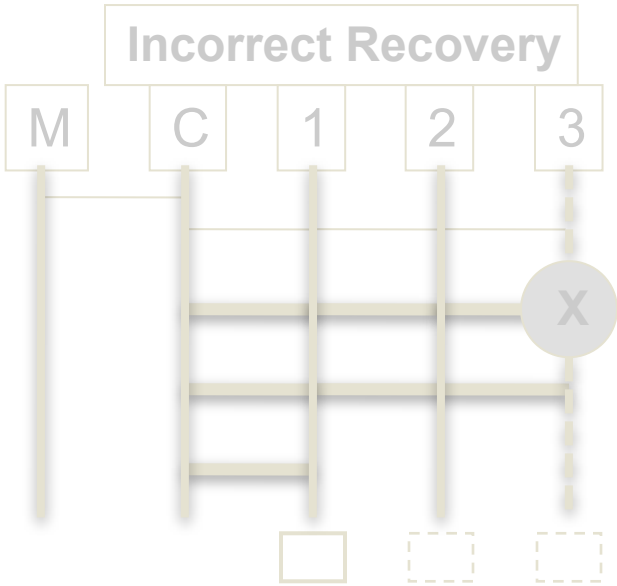

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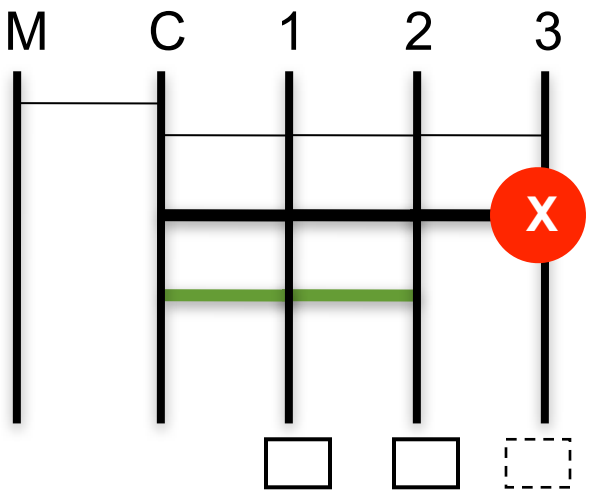

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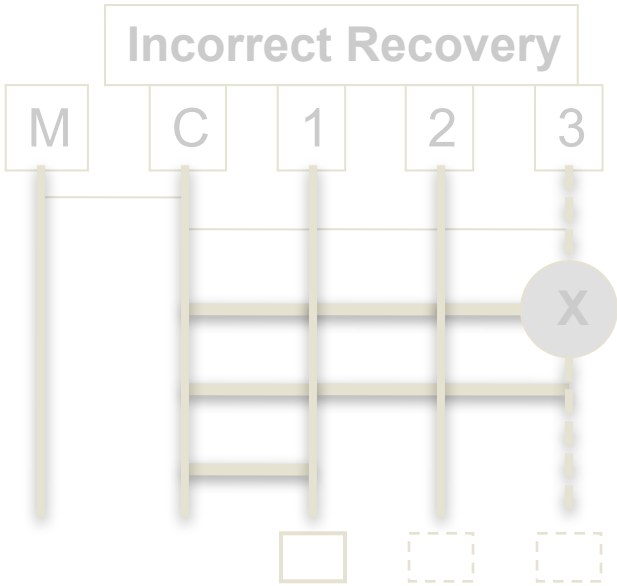

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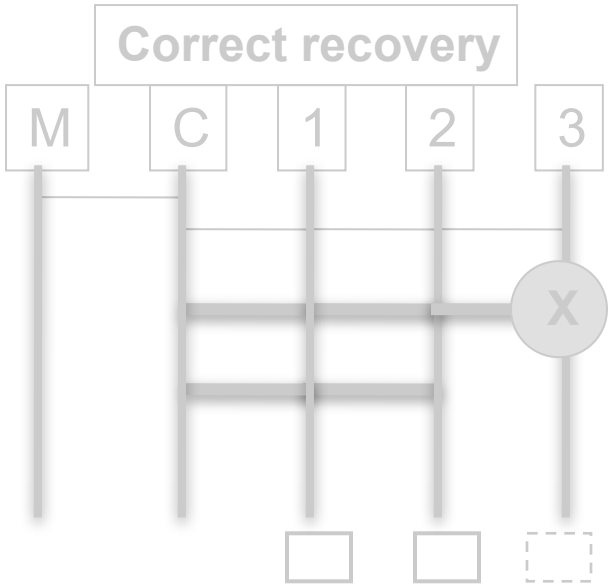
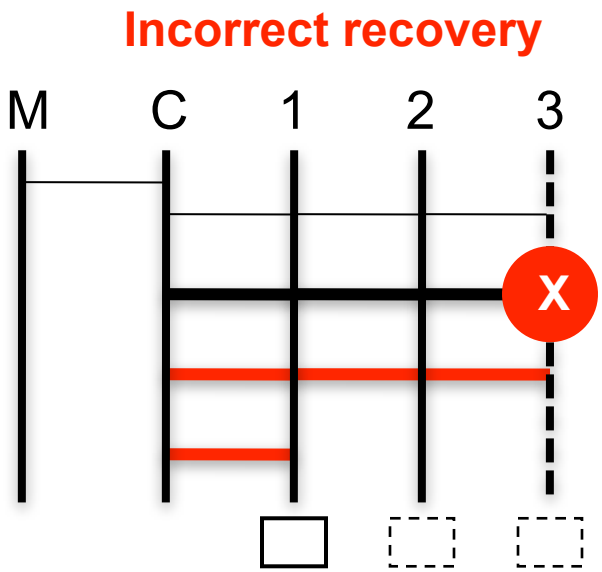
actualNodes(Block, Node)	
B	Node 1
B	Node 2

incorrectNodes(B, N) :- expectedNodes(B, N), NOT-IN actualNodes(B, N);





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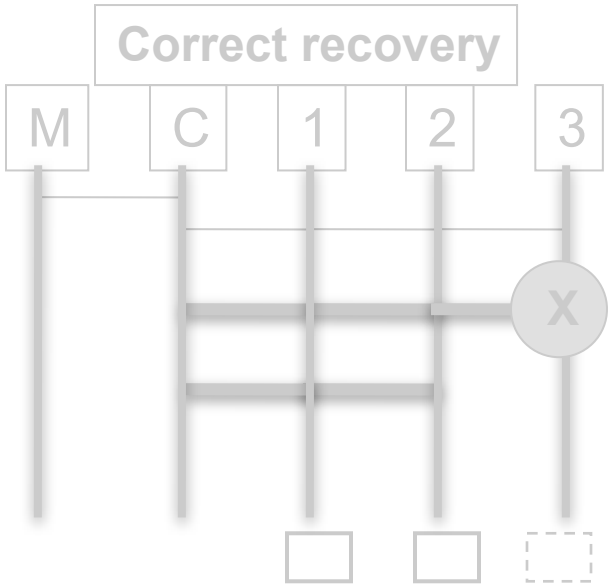

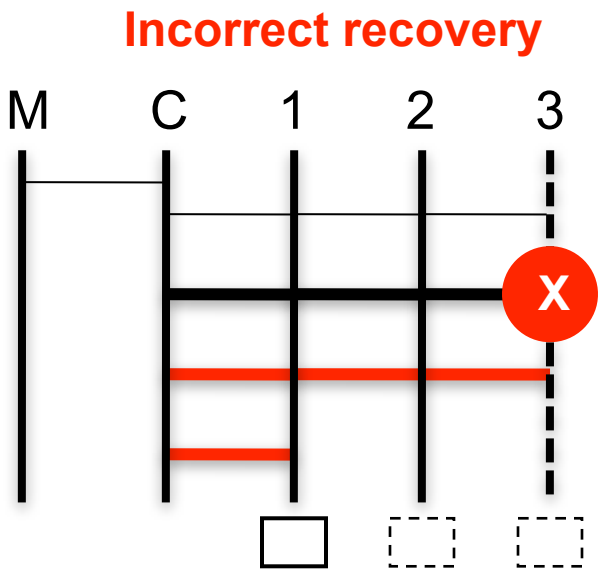

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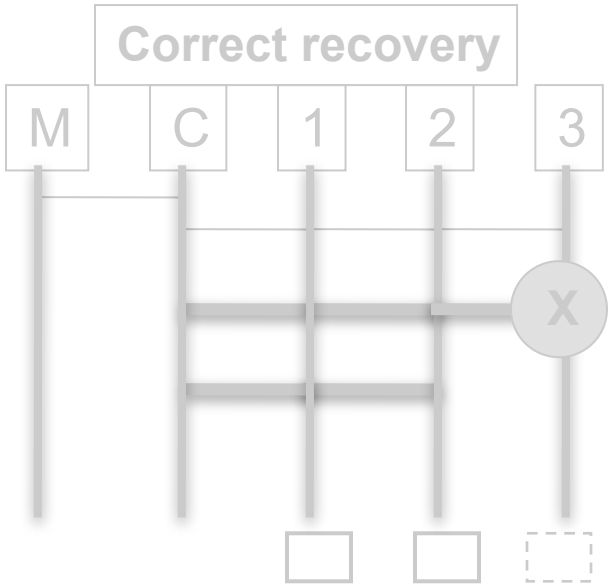

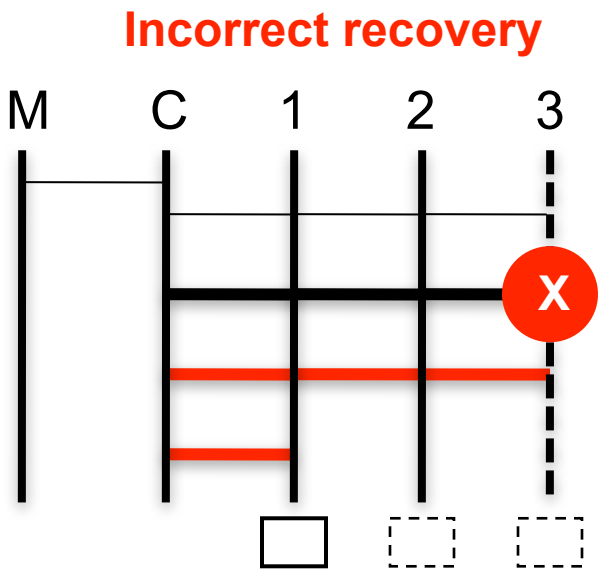

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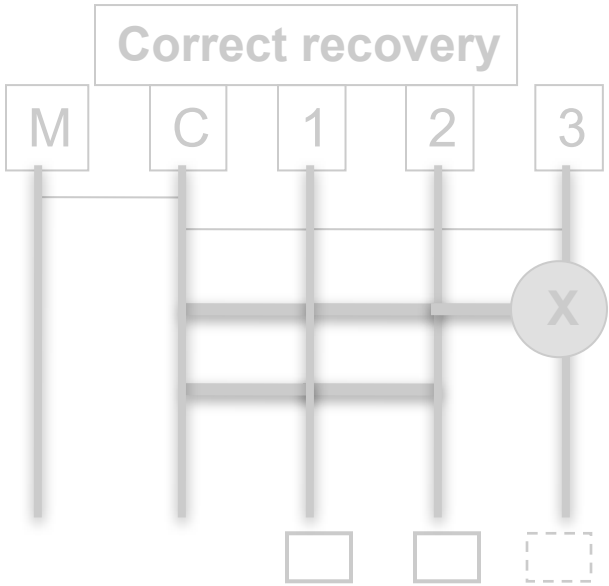

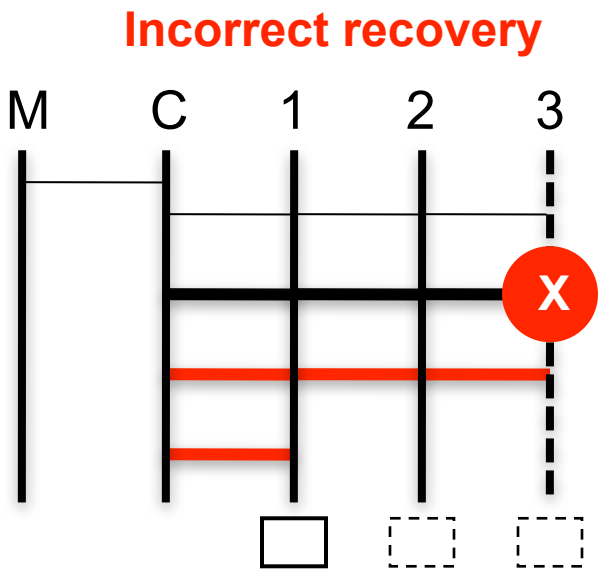

IncorrectNodes (Block, Node)	
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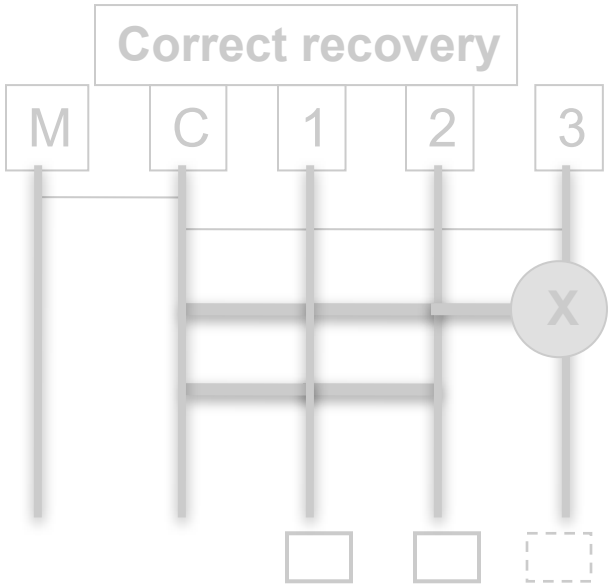

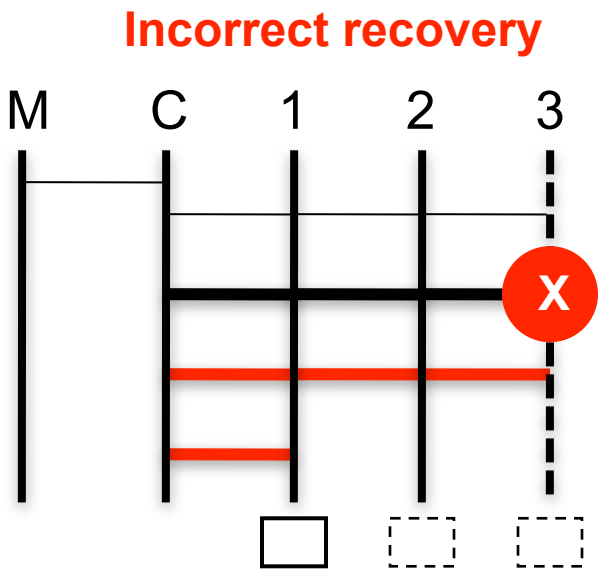

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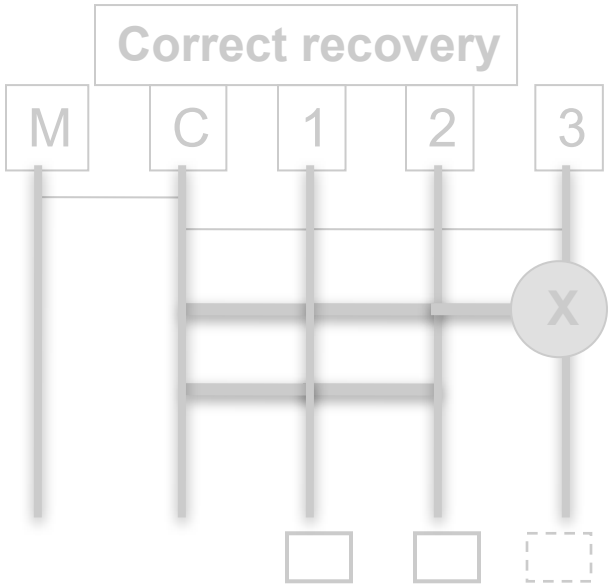

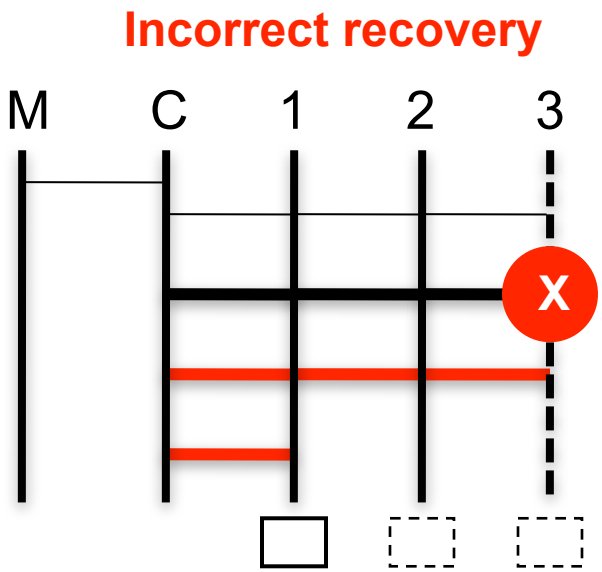

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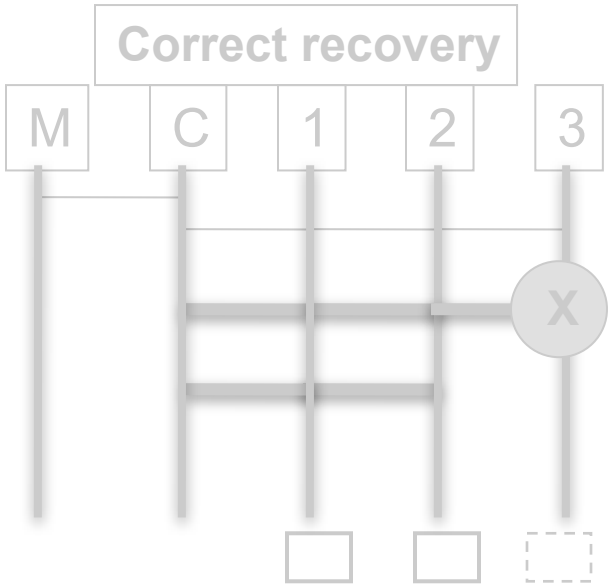
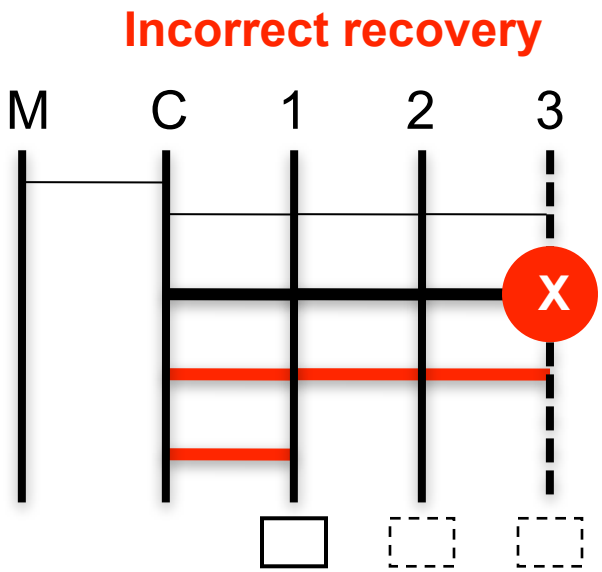
BUILD EXPECTATIONS





IncorrectNodes (Block, Node)	
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Expected Nodes (Block, Node)	
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B	Node 2

actualNodes(Block, Node)	
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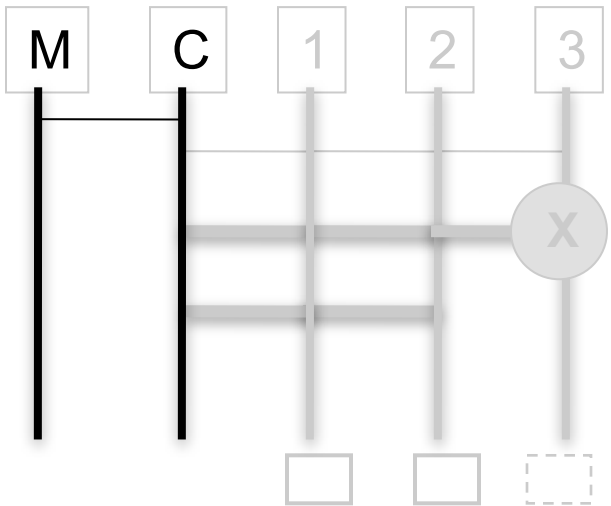
incorrectNodes(B, N) :- expectedNodes(B, N), NOT-IN actualNodes(B, N);

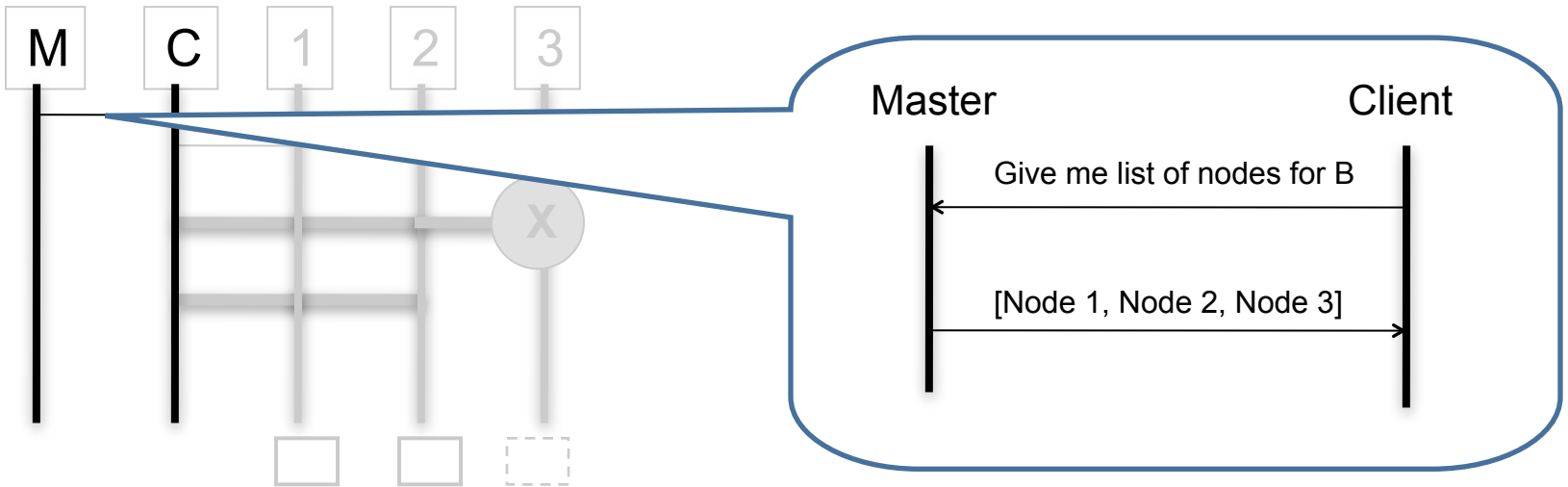
BUILD EXPECTATIONS

CAPTURE FACTS

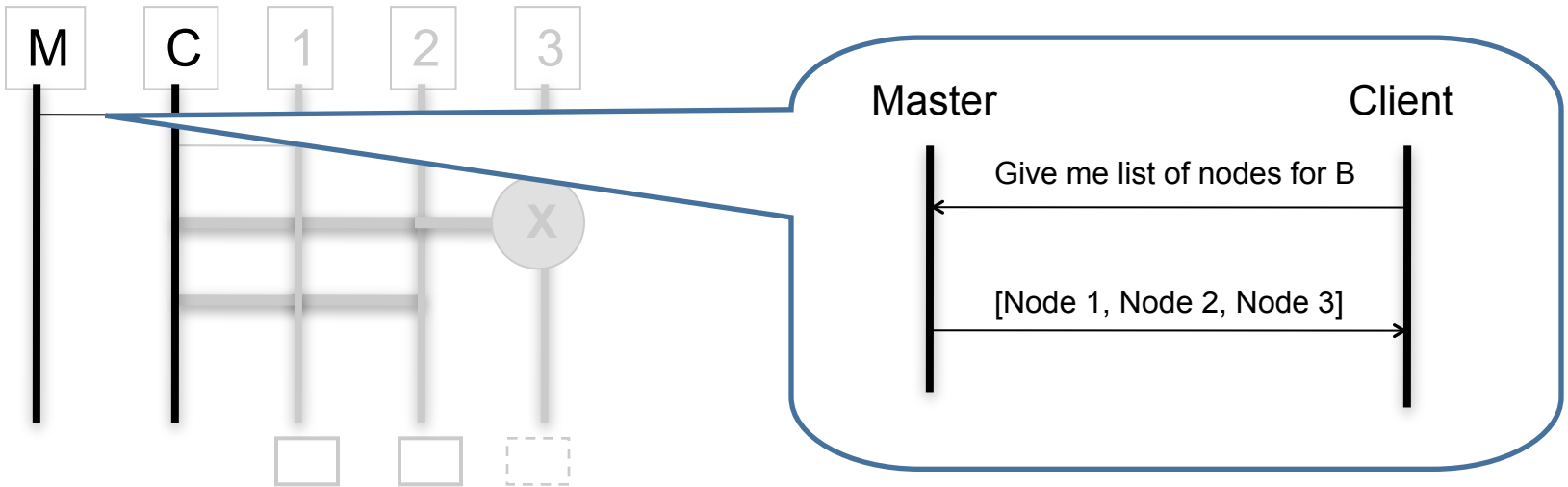
Building Expectations



Building Expectations

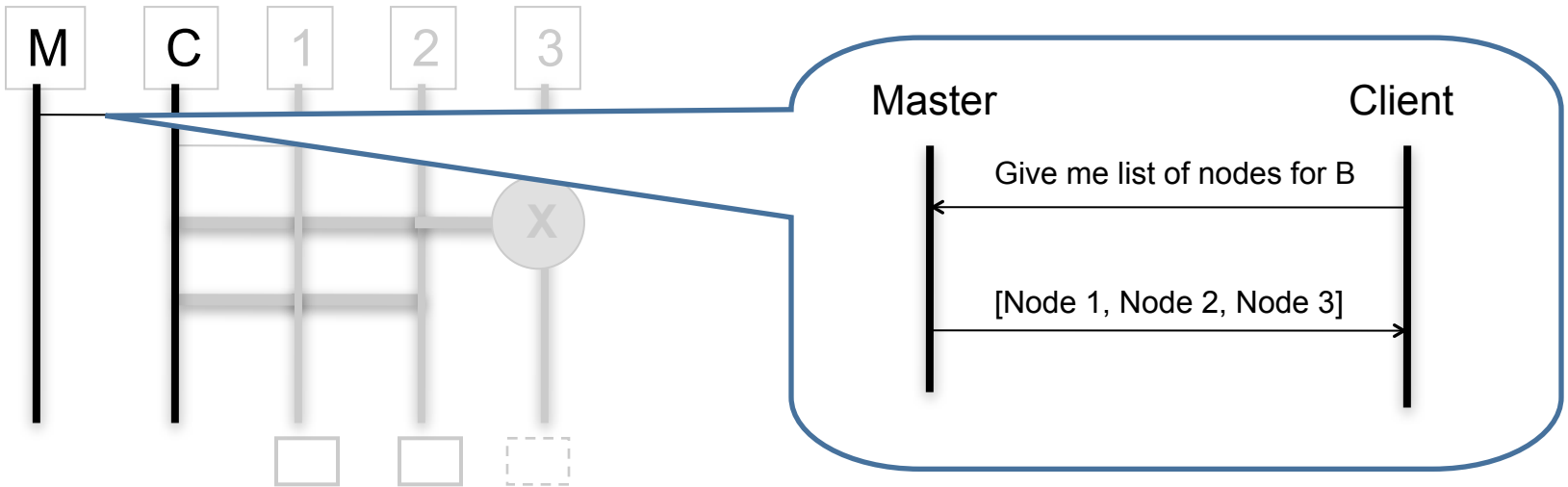


Building Expectations



expectedNodes(B, N) :- getBlockPipe(B, N);

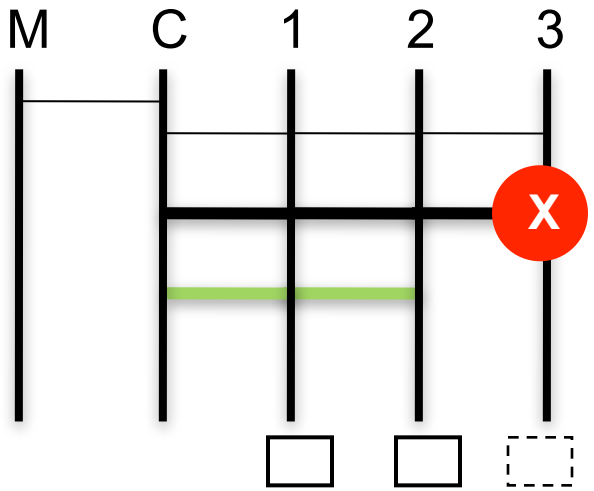
Building Expectations



expectedNodes(B, N) :- getBlockPipe(B, N);

Expected Nodes(Block, Node)	
B	Node 1
B	Node 2
B	Node 3

Updating Expectation



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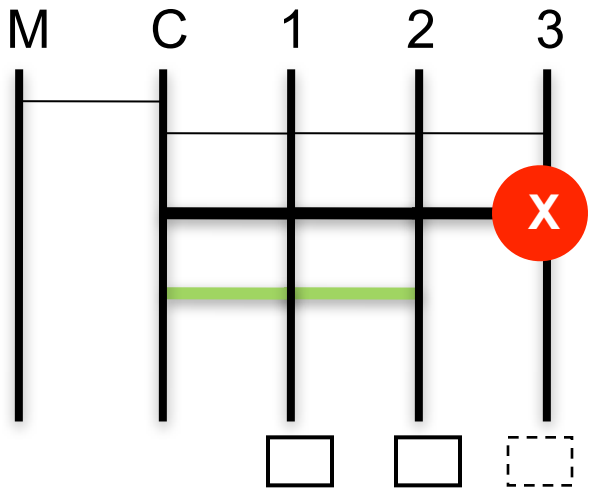

Expected Nodes(Block, Node)	
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DEL expectedNodes(B, N) :- fateCrashNode(N), writeStage(B, Stage),
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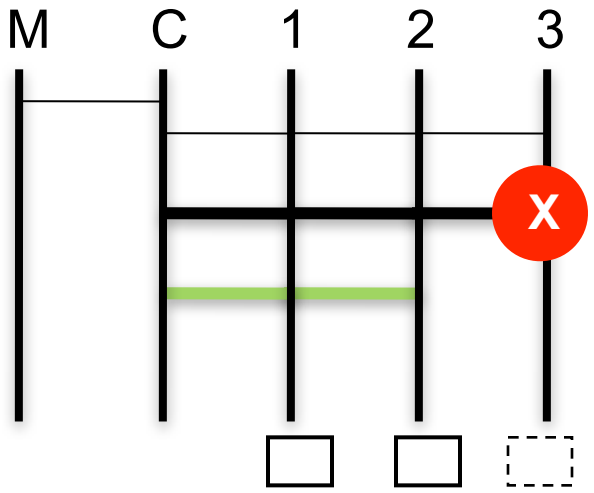
Updating Expectation



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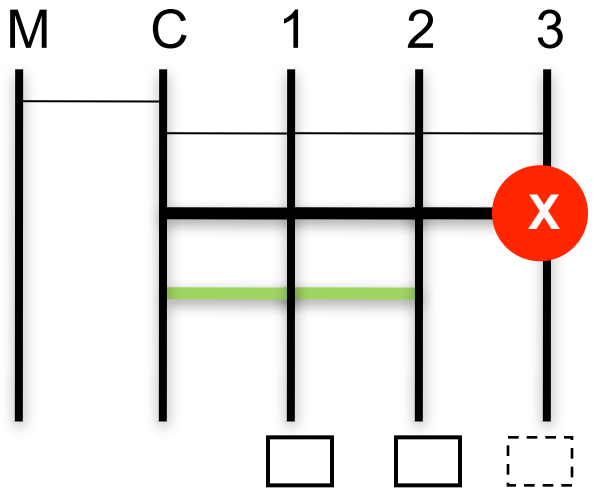

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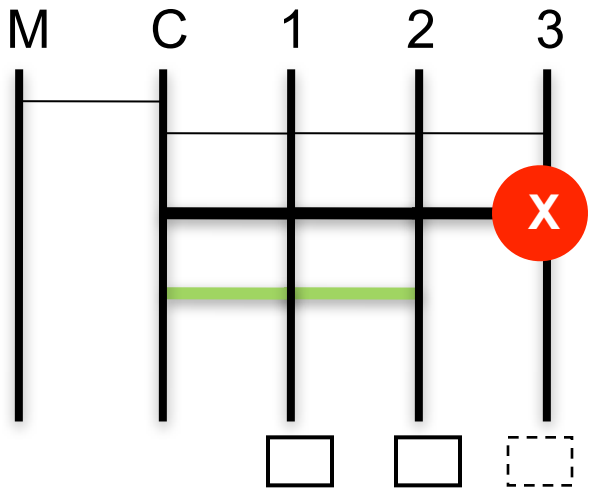

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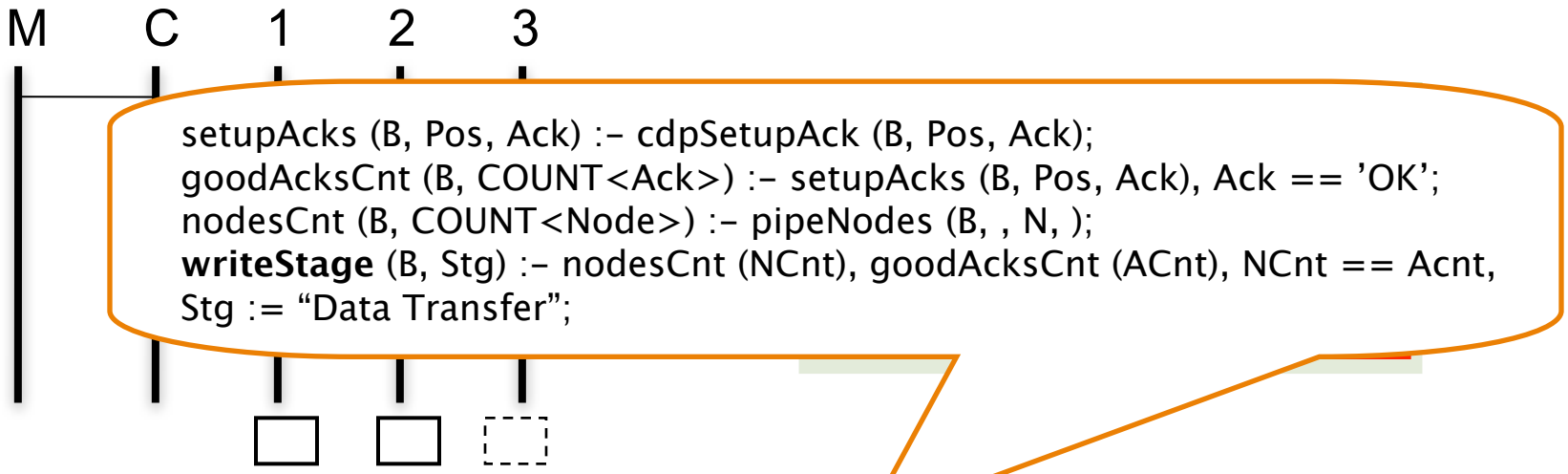
- "Client receives all acks from setup stage writeStage" → enter Data Transfer stage

Updating Expectation



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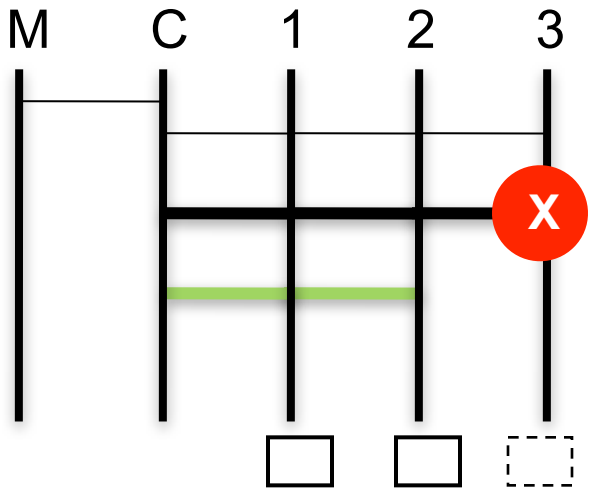

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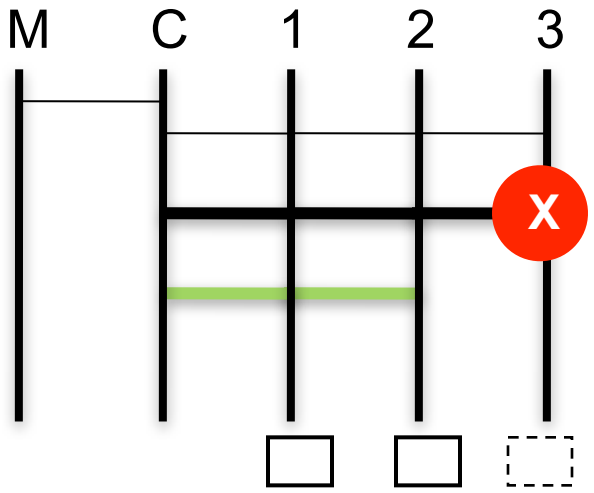

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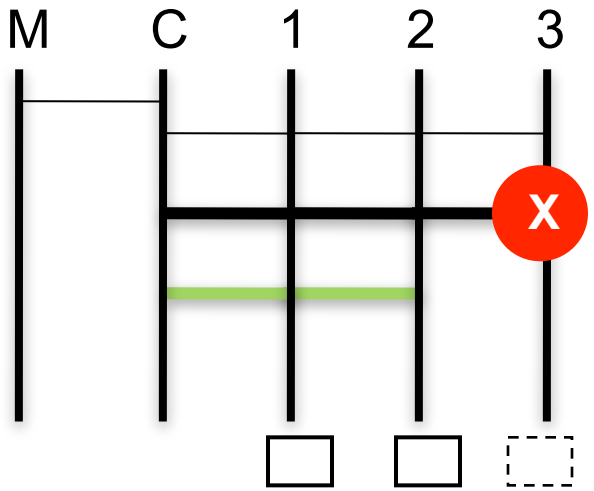
- "Client receives all acks from setup stage writeStage" → enter Data Transfer stage
- Precise failure events

Updating Expectation



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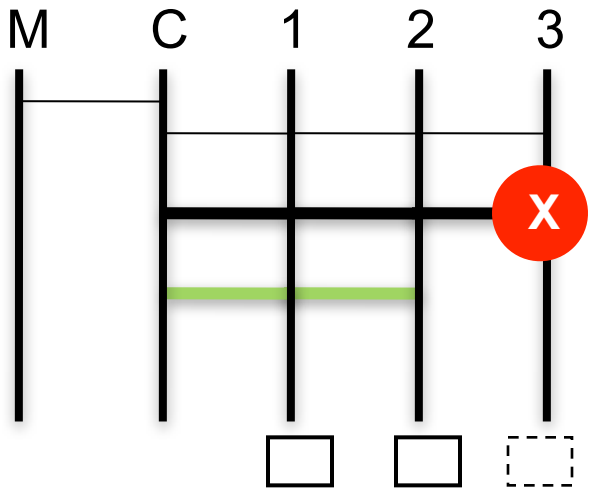
- Precise failure events
  - Different stages → different recovery behaviors → different specifications

Updating Expectation



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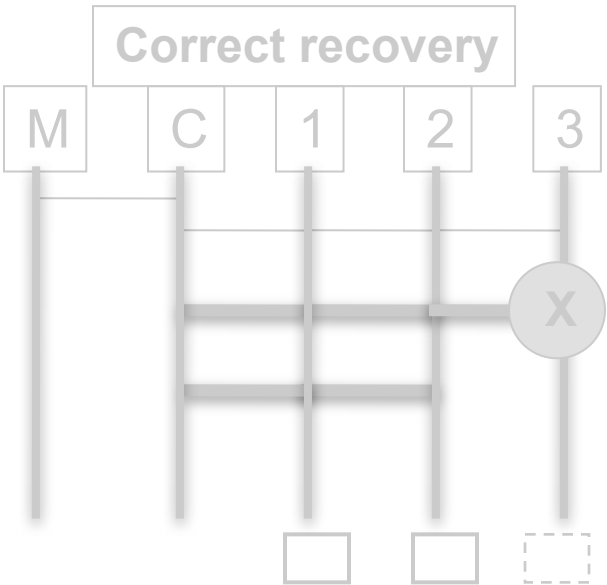
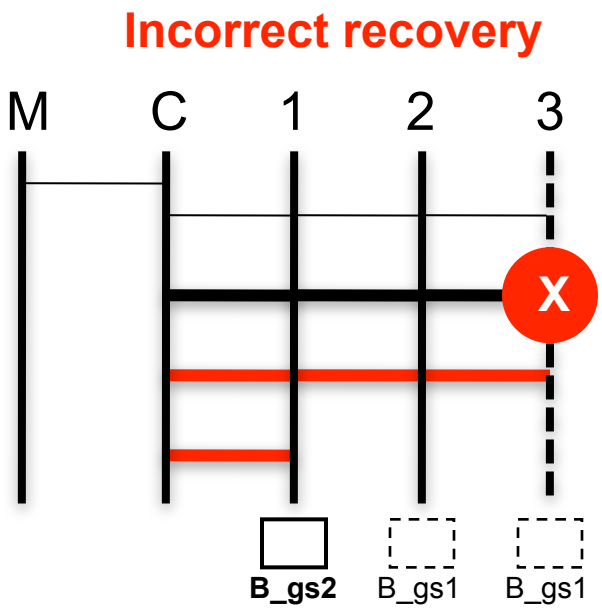
- "Client receives all acks from setup stage writeStage" → enter Data Transfer stage
- Precise failure events
  - Different stages → different recovery behaviors → different specifications
  - FATE and DESTINI must work hand in hand

Capture Facts





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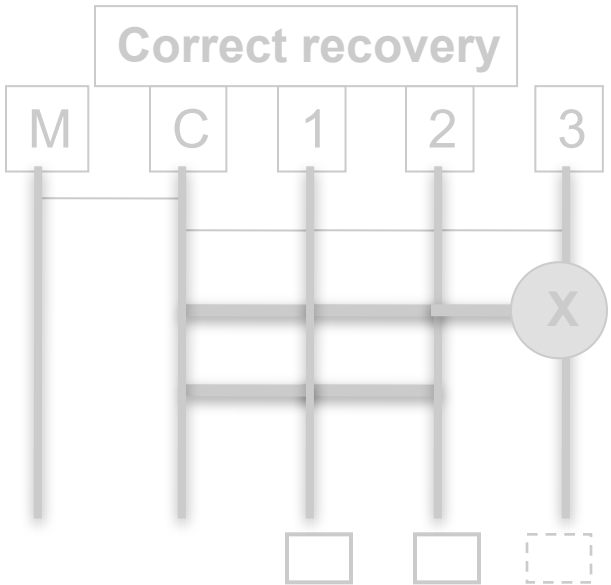
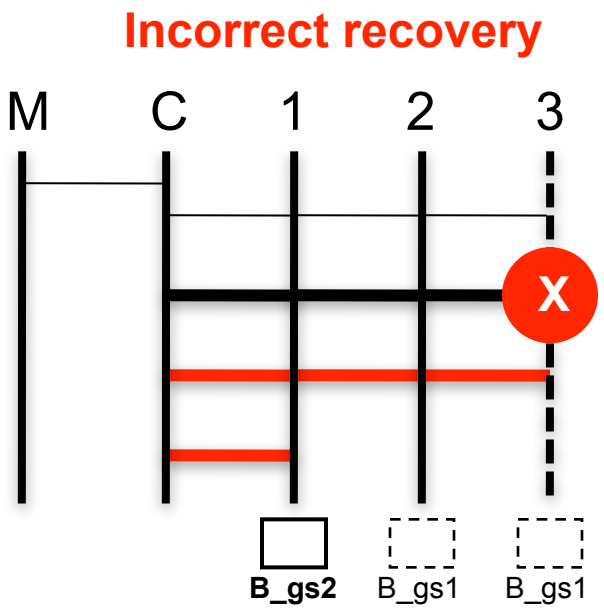
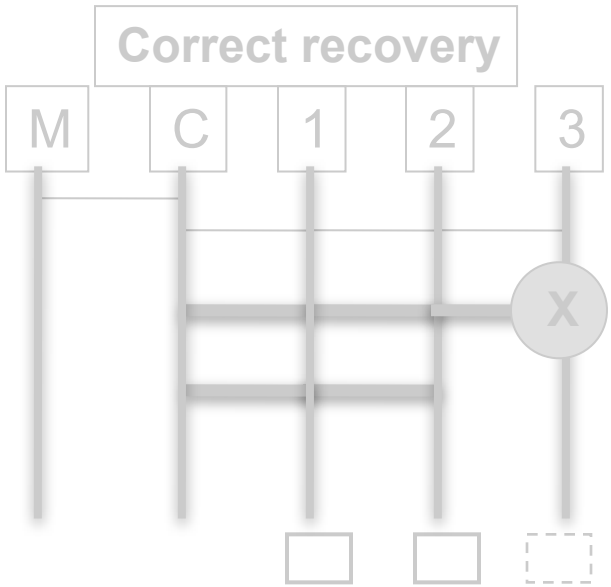
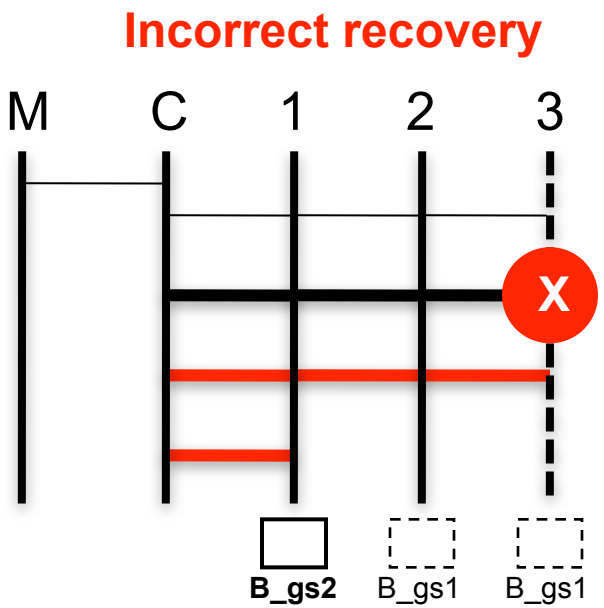




actualNodes(B, N) :- blocksLocation(B, N, Gs), latestGenStamp(B, Gs)

Capture Facts

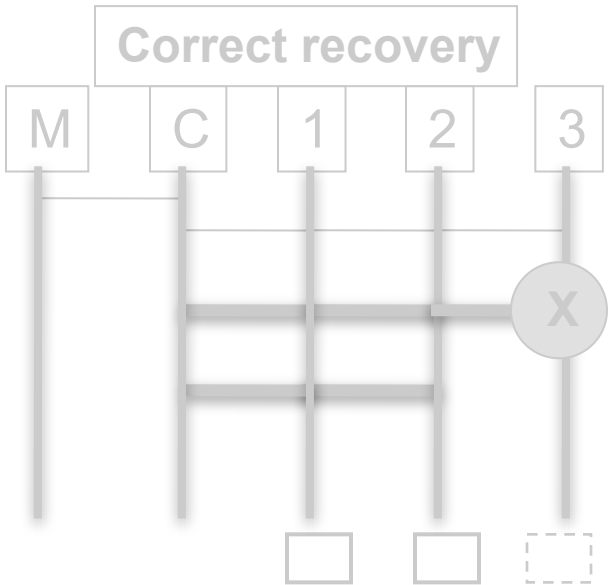


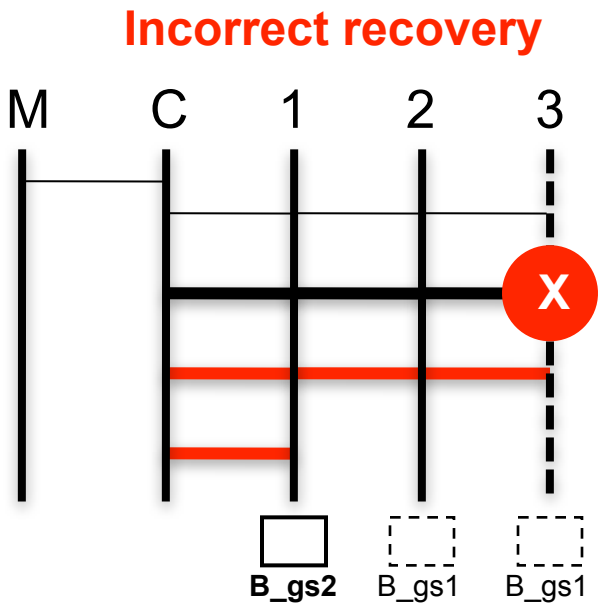


actualNodes(B, N) :- blocksLocation(B, N, Gs), latestGenStamp(B, Gs)

blocksLocations(B, N, Gs)		
B	Node 1	2
B	Node 2	1
B	Node 3	1

Capture Facts





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blocksLocations(B, N, Gs)		
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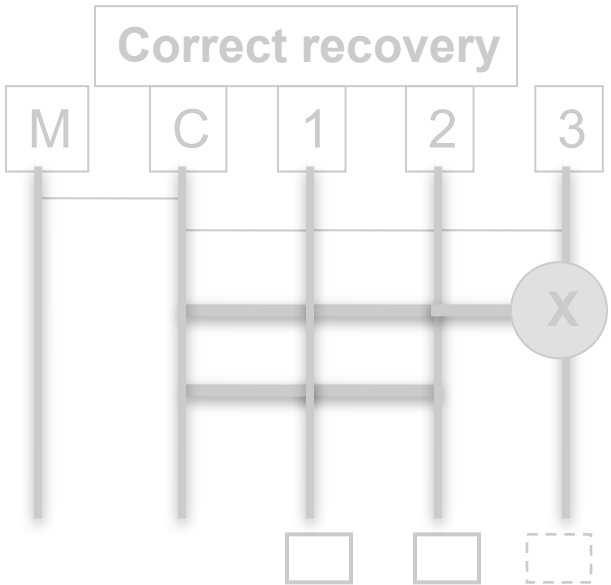
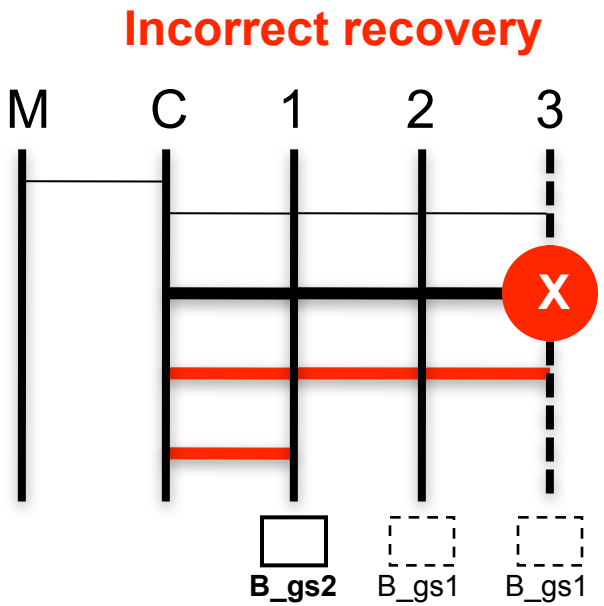
B	Node 3	1

latestGenStamp(B, Gs)	
B	2

Capture Facts





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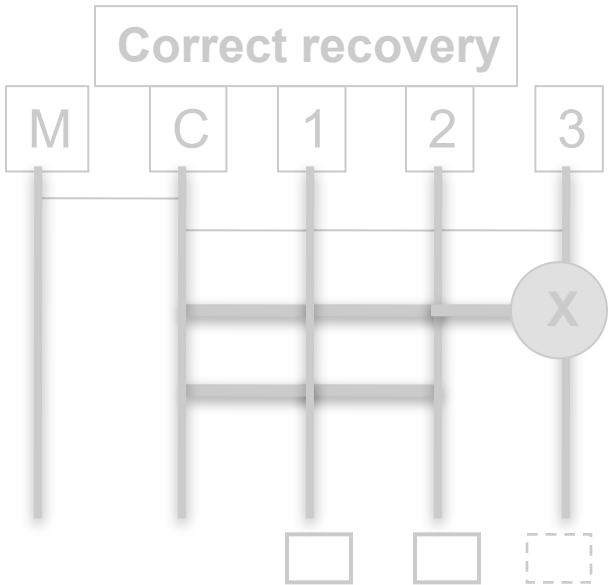
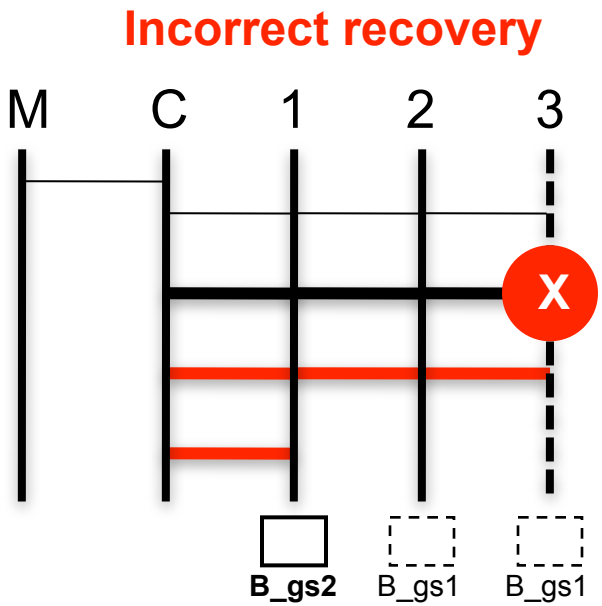
latestGenStamp(B, Gs)	
B	2

Capture Facts





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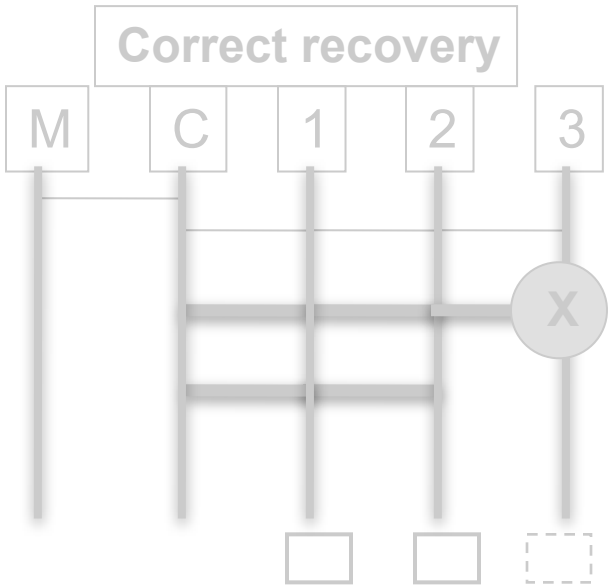
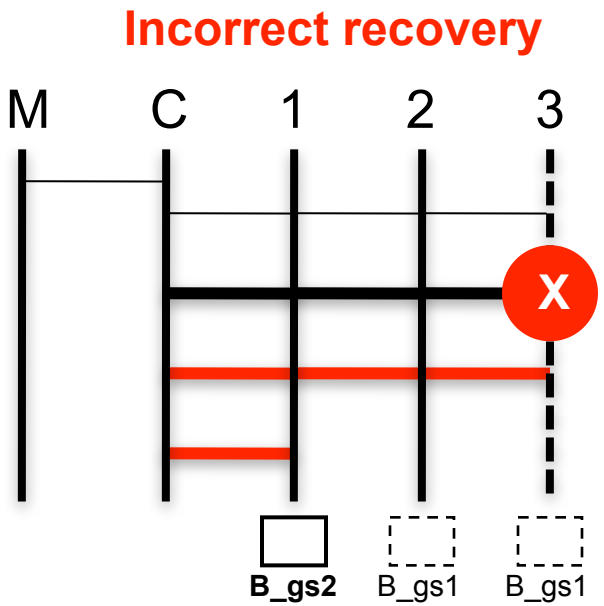
latestGenStamp(B, Gs)	
B	2

Capture Facts





actualNodes(B, N) :- blocksLocation(B, N, Gs), latestGenStamp(B, Gs)

actualNodes(Block, Node)	
B	Node 1

blocksLocations(B, N, Gs)		
B	Node 1	2
B	Node 2	1
B	Node 3	1

latestGenStamp(B, Gs)	
B	2

Violation and Check-Timing

incorrectNodes(B, N) :- expectedNodes(B, N), NOT-IN actualNodes(B, N),
cnpComplete(B) ;

IncorrectNodes (Block, Node)	
B	Node 2

ExpectedNodes (Block, Node)	
B	Node 1
B	Node 2

actualNodes(Block, Node)	
B	Node 1

Violation and Check-Timing

incorrectNodes(B, N) :- expectedNodes(B, N), NOT-IN actualNodes(B, N),
cnpComplete(B) ;

IncorrectNodes (Block, Node)	
B	Node 2

ExpectedNodes (Block, Node)	
B	Node 1
B	Node 2

actualNodes(Block, Node)	
B	Node 1

- There is a point in time where recovery is ongoing, thus specifications are violated

Violation and Check-Timing

incorrectNodes(B, N) :- expectedNodes(B, N), NOT-IN actualNodes(B, N),
cnpComplete(B) ;

IncorrectNodes (Block, Node)	
B	Node 2

ExpectedNodes (Block, Node)	
B	Node 1
B	Node 2

actualNodes(Block, Node)	
B	Node 1

- There is a point in time where recovery is ongoing, thus specifications are violated
- Need precise events to decide when the check should be done

Violation and Check-Timing

incorrectNodes(B, N) :- expectedNodes(B, N), NOT-IN actualNodes(B, N),
cnpComplete(B) ;

IncorrectNodes (Block, Node)	
B	Node 2

ExpectedNodes (Block, Node)	
B	Node 1
B	Node 2

actualNodes(Block, Node)	
B	Node 1

- There is a point in time where recovery is ongoing, thus specifications are violated
- Need precise events to decide when the check should be done
  - In this example, upon block completion

Rules

r1	**incorrectNodes** (B, N)	:–	cnpComplete (B), expectedNodes (B, N), NOT-IN actualNodes (B, N);
r2	pipeNodes (B, Pos, N)	:–	getBlkPipe (UFile, B, Gs, Pos, N);
r3	**expectedNodes** (B, N)	:–	getBlkPipe (UFile, B, Gs, Pos, N);
r4	DEL expectedNodes (B, N)	:–	fateCrashNode (N), pipeStage (B, Stg), Stg == 2, expectedNodes (B, N);
r5	setupAcks (B, Pos, Ack)	:–	cdpSetupAck (B, Pos, Ack);
r6	goodAcksCnt (B, CUUNT<Ack>)	:–	setupAcks (B, Pos, Ack), Ack == 'OK';
r7	nodesCnt (B, COUNT<Node>)	:–	pipeNodes (B, , N,);
r8	pipeStage (B, Stg)	:–	nodesCnt (NCnt), goodAcksCnt (ACnt), NCnt == Acnt, Stg := 2;
r9	blkGenStamp (B, Gs)	:–	dnpNextGenStamp (B, Gs);
r10	blkGenStamp (B, Gs)	:–	cnpGetBlkPipe (UFile, B, Gs, ,);
r11	diskFiles (N, File)	:–	fsCreate (N, File);
r12	diskFiles (N, Dst)	:–	fsRename (N, Src, Dst), diskFiles (N, Src, Type);
r13	DEL diskFiles (N, Src)	:–	fsRename (N, Src, Dst), diskFiles (N, Src, Type);
r14	fileTypes (N, File, Type)	:–	diskFiles(N, File), Type := Util.getType(File);
r15	blkMetas (N, B, Gs)	:–	fileTypes (N, File, Type), Type == metafile, Gs := Util.getGs(File);
r16	**actualNodes** (B, N)	:–	blkMetas (N, B, Gs), blkGenStamp (B, Gs);

Rules

r1	**incorrectNodes** (B, N)	:–	cnpComplete (B), expectedNodes (B, N), NOT-IN actualNodes (B, N);
r2	pipeNodes (B, Pos, N)	:–	getBlkPipe (UFile, B, Gs, Pos, N);
r3	**expectedNodes** (B, N)	:–	getBlkPipe (UFile, B, Gs, Pos, N);
r4	DEL expectedNodes (B, N)	:–	fateCrashNode (N), pipeStage (B, Stg), Stg == 2, expectedNodes (B, N);
r5	setupAcks (B, Pos, Ack)	:–	cdpSetupAck (B, Pos, Ack);
r6	goodAcksCnt (B, CUUNT<Ack>)	:–	setupAcks (B, Pos, Ack), Ack == 'OK';
r7	nodesCnt (B, COUNT<Node>)	:–	pipeNodes (B, , N,);
r8	pipeStage (B, Stg)	:–	nodesCnt (NCnt), goodAcksCnt (ACnt), NCnt == Acnt, Stg := 2;
r9	blkGenStamp (B, Gs)	:–	dnpNextGenStamp (B, Gs);
r10	blkGenStamp (B, Gs)	:–	cnpGetBlkPipe (UFile, B, Gs, ,);
r11	diskFiles (N, File)	:–	fsCreate (N, File);
r12	diskFiles (N, Dst)	:–	fsRename (N, Src, Dst), diskFiles (N, Src, Type);
r13	DEL diskFiles (N, Src)	:–	fsRename (N, Src, Dst), diskFiles (N, Src, Type);
r14	fileTypes (N, File, Type)	:–	diskFiles(N, File), Type := Util.getType(File);
r15	blkMetas (N, B, Gs)	:–	fileTypes (N, File, Type), Type == metafile, Gs := Util.getGs(File);
r16	**actualNodes** (B, N)	:–	blkMetas (N, B, Gs), blkGenStamp (B, Gs);

Rules

r1	**incorrectNodes** (B, N)	:-	cnpComplete (B), expectedNodes (B, N), NOT-IN actualNodes (B, N);
r2	pipeNodes (B, Pos, N)	:-	getBlkPipe (UFile, B, Gs, Pos, N);
r3	**expectedNodes** (B, N)	:-	getBlkPipe (UFile, B, Gs, Pos, N);
r4	DEL expectedNodes (B, N)	:-	fateCrashNode (N), pipeStage (B, Stg), Stg == 2, expectedNodes (B, N);
r5	setupAcks (B, Pos, Ack)	:-	cdpSetupAck (B, Pos, Ack);
r6			
r7			
r8			
r9			
r1			
r1			
r1			
r1			
r14	fileTypes (N, File, Type)	:-	diskFiles(N, File), Type := Util.getType(File);
r15	blkMetas (N, B, Gs)	:-	fileTypes (N, File, Type), Type == metafile, Gs := Util.getGs(File);
r16	**actualNodes** (B, N)	:-	blkMetas (N, B, Gs), blkGenStamp (B, Gs);

- Capture Facts, Build Expectation from IO events
  - No need to interpose internal functions
- Specification Reuse
  - For the first check, # rules : #check is 16:1
  - Overall, #rules: # check ratio is 3:1

Outline

- ✓ Introduction
- ✓ FATE
- ✓ DESTINI
- Evaluation
- Summary

Evaluation

- FATE: 3900 lines, DESTINI: 1200 lines
- Applied FATE and DESTINI to three cloud systems
  - HDFS, ZooKeeper, Cassandra
- 40,000 unique combination of failures
- Found 16 new bugs, reproduced 74 bugs
- 74 recovery specifications
  - 3 lines / check

Bugs found

- Reduced availability and performance
- Data loss due to multiple failures
- Data loss in log recovery protocol
- Data loss in append protocol
- Rack awareness property is broken

Conclusion

- FATE explores multiple failure systematically
- DESTINI enables concise recovery specifications
- FATE and DESTINI: a unified framework
  - Testing recovery specifications requires a failure service
  - Failure service needs recovery specifications to catch recovery bugs

Thank you!

QUESTIONS?

Berkeley Orders of Magnitude
http://boom.cs.berkeley.edu

The Advanced Systems Laboratory
http://www.cs.wisc.edu/adsl

Downloads our full TR paper from these websites