

Analysis of Concurrent and Distributed Programs

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(1) Introduction

- Course logistics
- Lecture content
- Course projects

Overview of concurrency

- Paradigms
- Concepts

Interactions

Concurrent Programming: Paradigms

Multiple computations *that may/may not influences one another*

- Parallelism (SIMD, MIMD, ...)
 - Independent computation on multiple threads/processes on independent data
- Distributed computing
 - Independent computation on multiple machines with message passing
- Asynchronous programming
 - Multiple tasks on single/multiple threads that may share memory
 - Event driven systems
- Shared memory concurrency
 - Multiple threads that communicate by shared memory

Concurrent Programming: Motivation

Pros

- + Concurrency improves performance

Cons

- Concurrent programming is hard
- May result in tricky bugs in programs

Requires careful analysis

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This course !

Example

$$X = 0;$$

$$X = X + 1; \parallel X = X + 1;$$

What is the final value(s) of X ?

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What is the final value(s) of X ?

- Expected: $X = 2$.

Example

$X = 0;$

$a = X;$	\parallel	$b = X;$
$a = a + 1;$	\parallel	$b = b + 1;$
$X = a;$	\parallel	$X = b;$

Example: Execution (1)

$X = 0;$

$a = X;$	$//\ 0$	$b = X;$
$a = a + 1;$		$b = b + 1;$
$X = a;$		$X = b;$

Example: Execution (1)

$X = 0;$

$a = X;$	// 0	$b = X;$
$a = a + 1;$		$b = b + 1;$
$X = a;$	// 1	$X = b;$

Example: Execution (1)

$X = 0;$

$a = X;$	$//\ 0$	$b = X;$	$//\ 1$
$a = a + 1;$		$b = b + 1;$	
$X = a;$	$//\ 1$	$X = b;$	

Example: Execution (1)

$X = 0;$

$a = X;$	// 0		$b = X;$	// 1
$a = a + 1;$			$b = b + 1;$	
$X = a;$	// 1		$X = b;$	// 2

Example: Execution (2)

$X = 0;$

$a = X;$	$//\ 0$	$b = X;$	$//\ 0$
$a = a + 1;$		$b = b + 1;$	
$X = a;$		$X = b;$	

Example: Execution (2)

$X = 0;$

$a = X;$	$//\ 0$	$b = X;$	$//\ 0$
$a = a + 1;$		$b = b + 1;$	
$X = a;$	$//\ 1$	$X = b;$	$//\ 1$

Example

$$X = 0;$$

$$X = X + 1; \parallel X = X + 1;$$

What is the final value(s) of X ?

Example

$$X = 0;$$

$$X = X + 1; \quad || \quad X = X + 1;$$

What is the final value(s) of X ?

- Expected: $X = 2$.
- Reality: $X \in \{1, 2\}$

What are the semantics of these primitives?

Analysis Questions

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Given a concurrent program and an outcome,

What are the semantics of these primitives?

Given a concurrent program and an outcome,

- Is it correct?
- Is it a bug?
- What are common concurrency bugs?
- Will it happen in *all* execution?
- Will it happen in *at least one* execution?

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Given a concurrent program and an outcome,

- Is it correct?
- Is it a bug?
- What are common concurrency bugs?
- Will it happen in *all* execution?
- Will it happen in *at least one* execution?

After finding a bug:

- How to fix it?
- Is it the best way to fix it?
- Is it affecting performance?

Going Back to the Example

$X = 0;$

$a = X;$	// 0		$b = X;$	// 1
$a = a + 1;$			$b = b + 1;$	
$X = a;$	// 1		$X = b;$	// 2



$X = 0;$

$a = X;$	// 0		$b = X;$	// 0
$a = a + 1;$			$b = b + 1;$	
$X = a;$	// 1		$X = b;$	// 1



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$X = 0;$

$a = X; \quad // 0$	$b = X; \quad // 0$
$a = a + 1;$	$b = b + 1;$
$X = a; \quad // 1$	$X = b; \quad // 1$

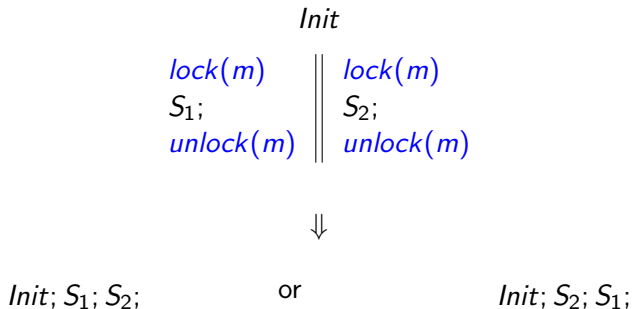


Solution: use lock/unlock primitives.

$X = 0;$

$lock(m)$	$lock(m)$
$a = X;$	$b = X;$
$a = a + 1;$	$b = b + 1;$
$X = a;$	$X = b;$
$unlock(m)$	$unlock(m)$

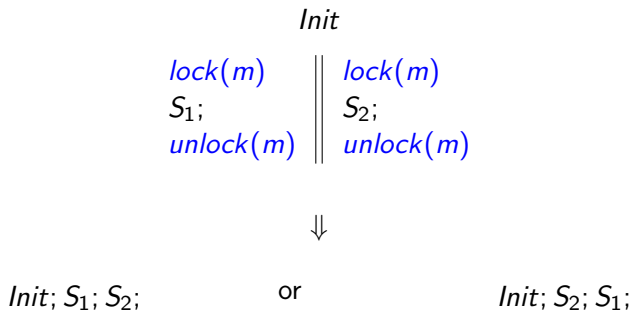
Solution: Tradeoff



lock/unlock

- Reduces concurrency

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lock/unlock

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Goal: minimal lock/unlock for correct programming

Locking mechanism.

- Primitive: mutex
- Properties: mutual exclusion

Errors

- Datarace
- Atomicity violation

Pitfalls

- Deadlock
- Livelock
- Termination

Lock free programming

- Non-blocking concurrency

Concurrency analysis for multithreaded programs

- Race detection
- Atomicity violation detection

Analysis techniques

- Static and dynamic analysis
- Model checking
- testing

Sequential consistency (SC)

Weak memory (Non-SC) models

- TSO
- PSO
- RMO
- RA
- ...

Analysis of weak memory programs

- Many flavors of concurrency
 - Single-threaded/multi-threaded asynchronous
 - Event driven
 - Distributed

Distributed Programming

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- Concurrency analysis for distributed programs

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- Replicated systems: Linearizability & CAP Theorem

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