EE392C Emerging Applications: Verification Applications

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Outline

- Motivation
- Beyond simulation and testing
- Model checking
- Theorem proving
- Hardware support
- Summary

Motivation

- Mission-critical systems
  - Ex. Space shuttle, medical instruments
- Complex, expensive systems
  - Ex. Telephone switching systems, arithmetic units in CPU
- Used widely for both software and hardware systems

Beyond Simulation and Testing

- Simulation and testing require the development of inputs (stimuli), and observation of outputs
  - Only as good as your test cases
- Adequate for many commercial applications, but not good enough for critical systems and such
- Formal verification exhaustively *proves* the correctness
  - Much more time consuming and complex

Model Checking

- Create a finite state description of a system to be verified
- Exhaustively search the finite state space to determine if a specification is true
- 3 main steps in model checking:
    1. Create the model
    2. Specify properties that must hold
    3. Verify model against specifications

Model Checking

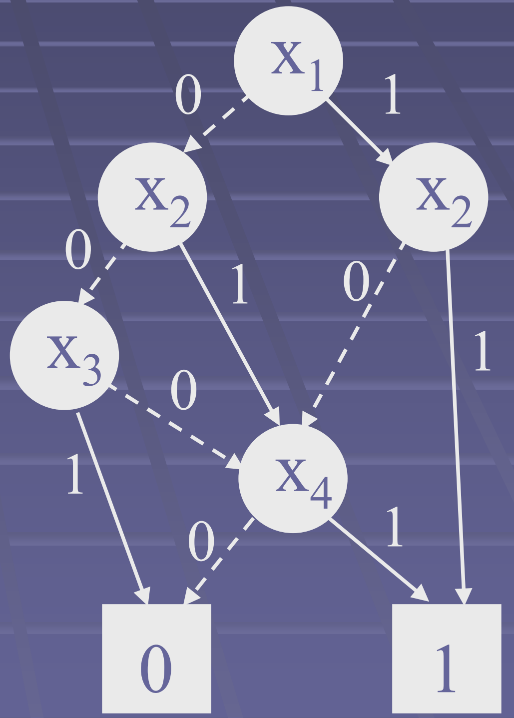
- Verification should always terminate with a true or false condition
  - But, complexity of the model (number of finite states) can explode
  - Process of verification is automatic, but can be prohibitively long
    - A lot of research on state reduction, which is not of interest to us
    - But, perhaps we can exploit parallelism

Model Checking

- Large state space can be partitioned into subspaces
  - Subspaces can be processed in parallel – great for TLP
- Tend to be memory bound processes – large ratio of memory to arithmetic instructions
  - Access patterns mostly random – little to no locality to exploit
    - Perhaps software prefetching can help

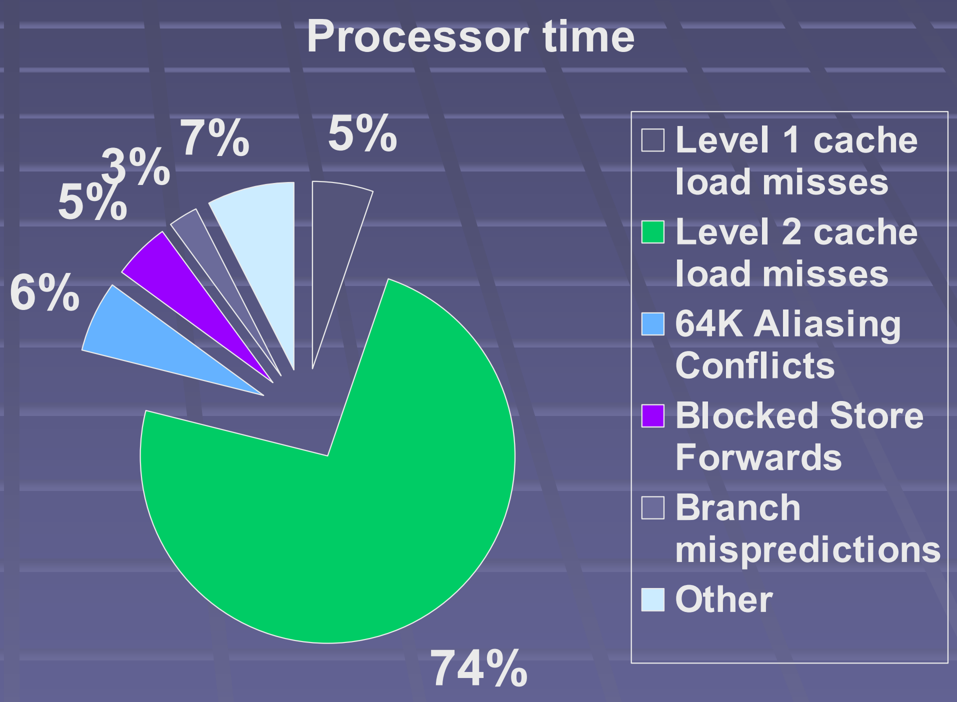
Model Checking – Case Study

- Reduced Ordered Binary Decision Diagrams: a fundamental data structure in model checking
- ROBDDs are produced through the repeated application of:
  - Redundant test elimination
  - Equivalent sub-graph sharing
- We investigated the application characteristics of a popular BDD package
  - BuDDy package version 2.2
  - Compiled with Intel –O3 compiler
  - Intel P4-2.4 GHz using VTune
  - BuDDy test cases for model-checking



Model Checking – Results

- As expected, it was almost completely memory bound
  - 80% of time was spent on cache misses
  - CPI was 6.5
  - Read bus utilization: 8.38%
- To find equivalent nodes, code hashes all nodes into a large hash table
  - Table is too large to fit into the cache, and accesses are random

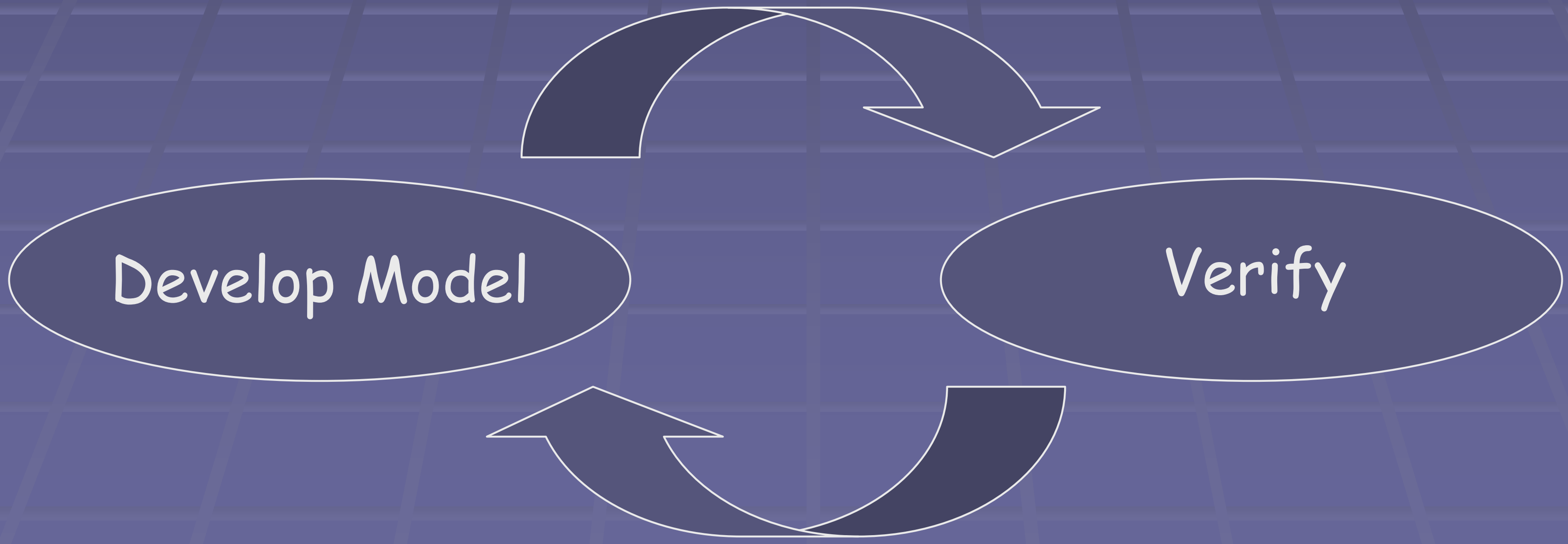


Theorem Provers

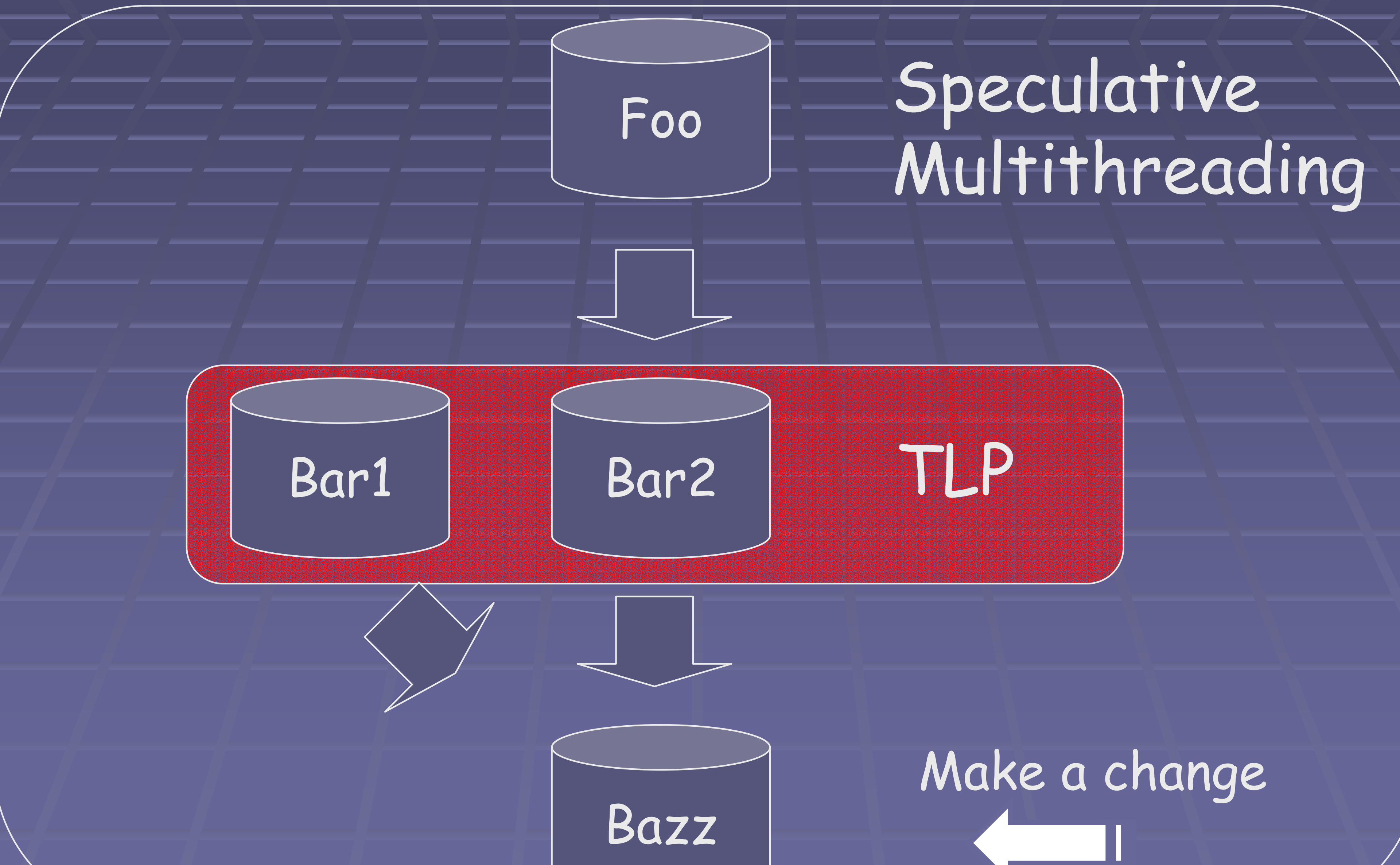
- Inductive and deductive verification techniques
- PROS: No state explosion
- CONS: It’s hard! (And requires more programmer intervention)

Case Study: ACL2

- Developed in 1989 at UT-Austin and AMD
- Shares ancestry with Stanford's PVS
- Written in Common Lisp



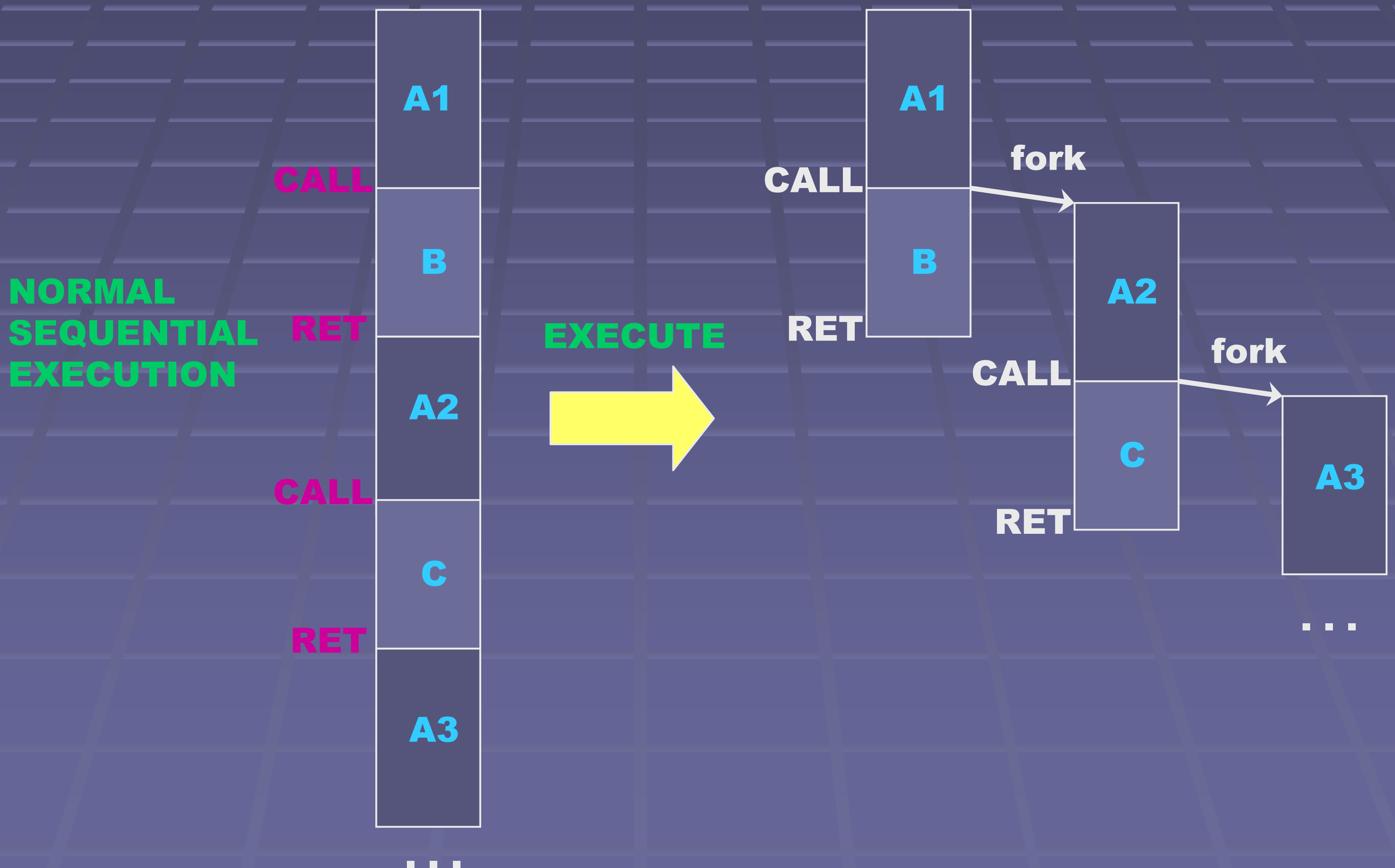
TLP Opportunities in ACL2



Hardware support for bug detection (Oplinger & Lam 2002)

- Hardware support for fine-grained transactions
  - Software marks beginning of transaction
  - All further side-effects (memory and register) are buffered
  - Software decides when to either commit or abort the transaction
- Use Thread Level Speculation to parallelize monitoring code
  - Very effective because monitoring code is typically independent from original code

Procedural Thread-level Speculation (TLS)



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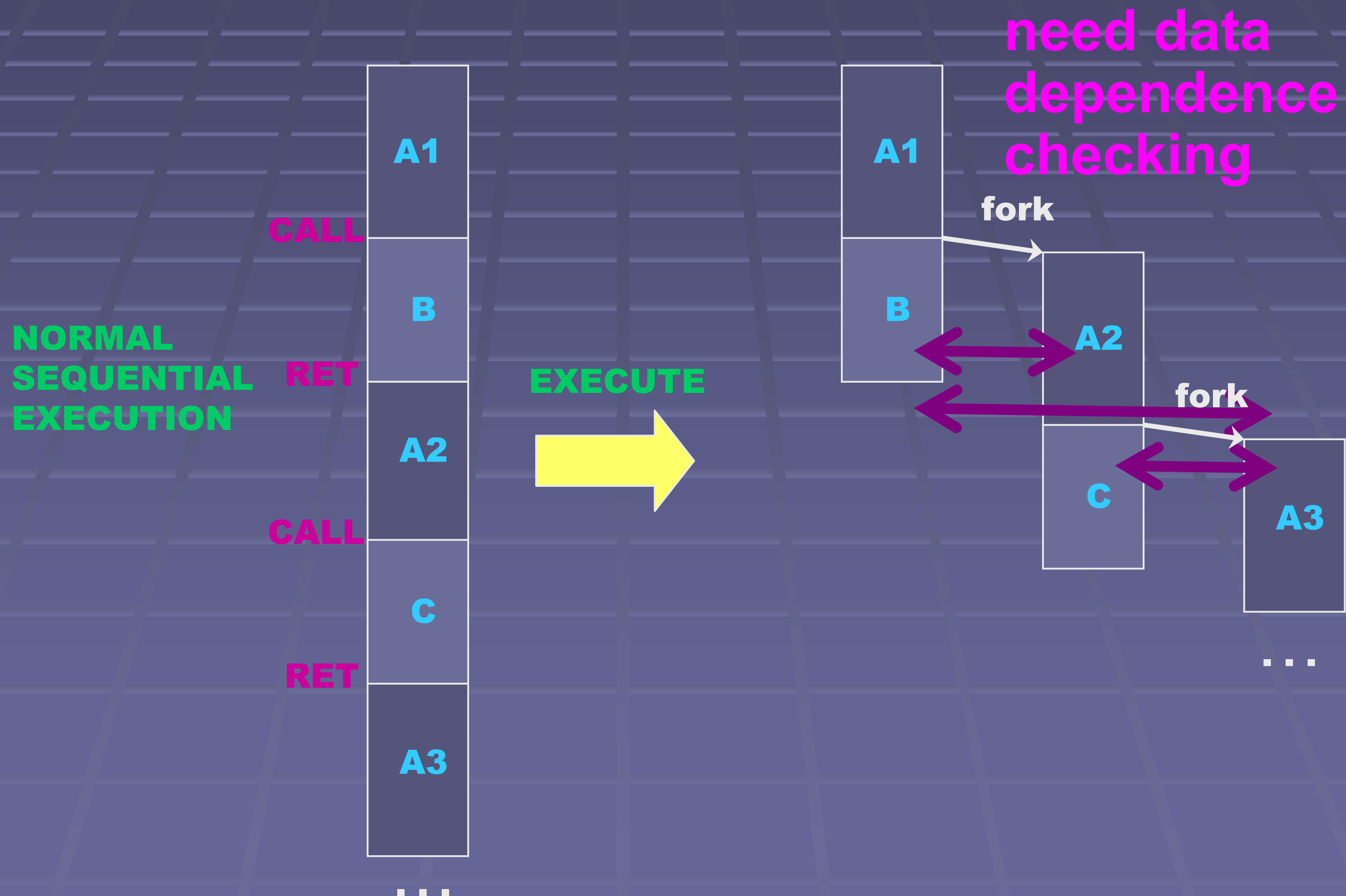

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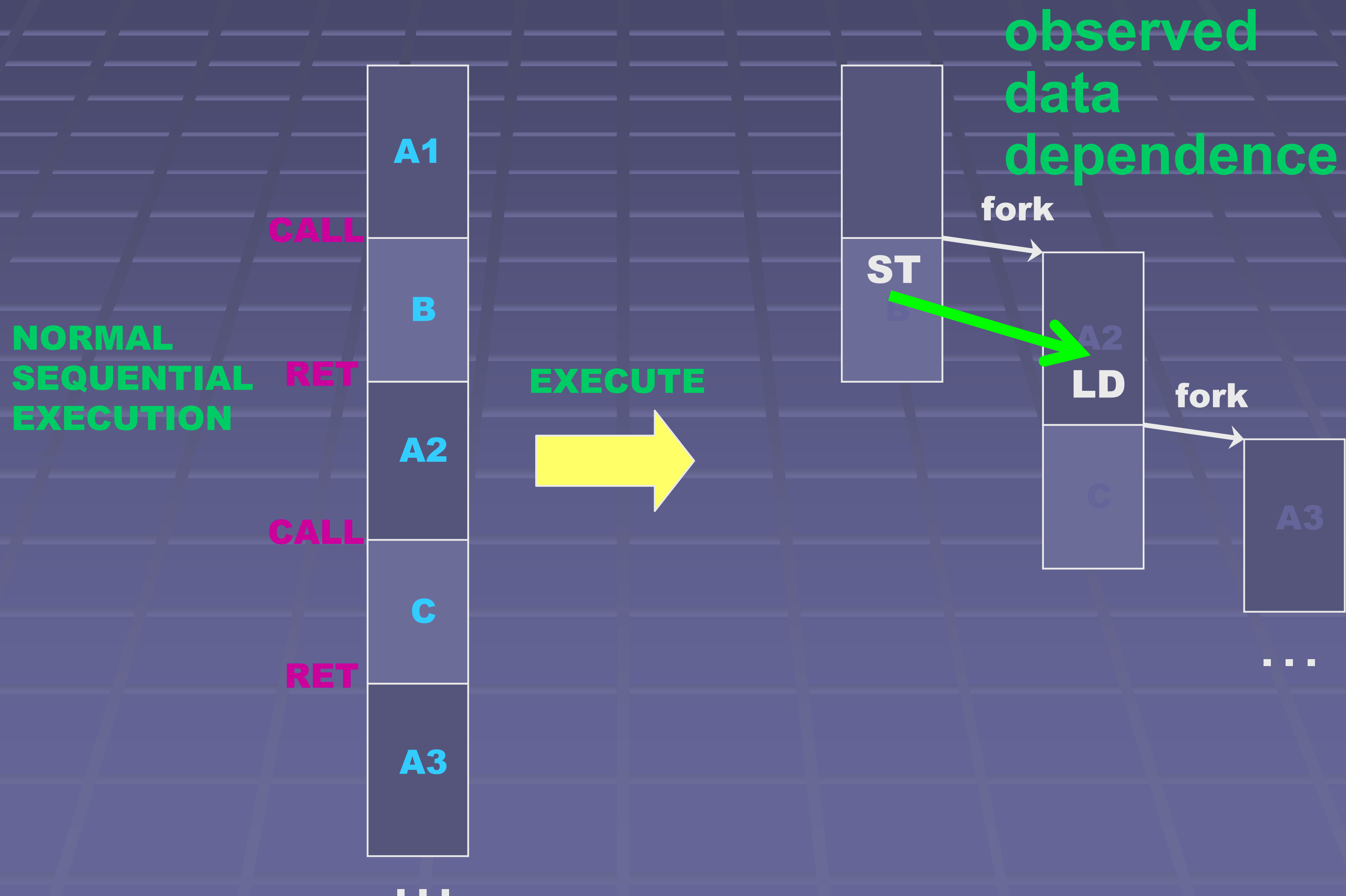

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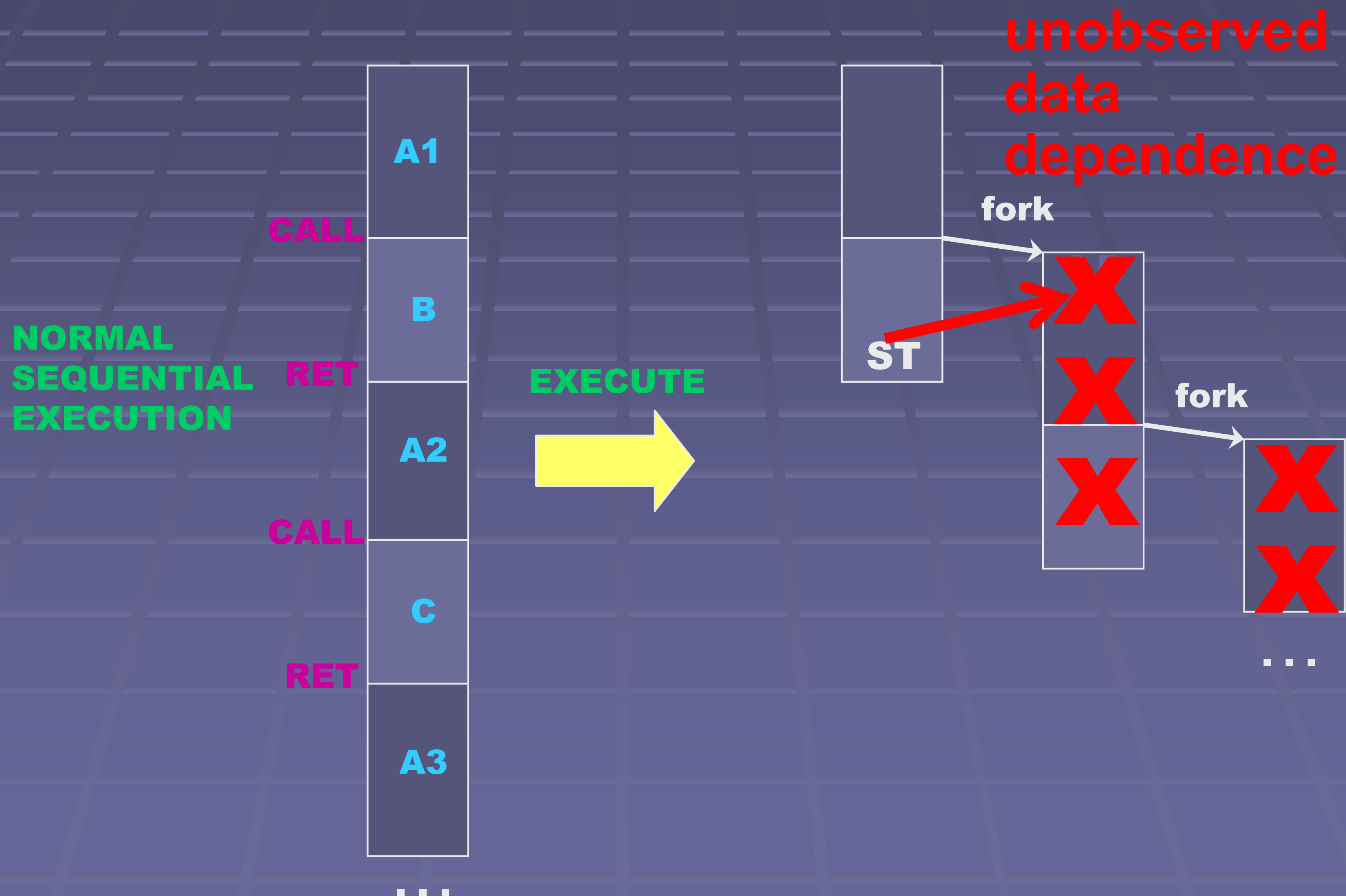

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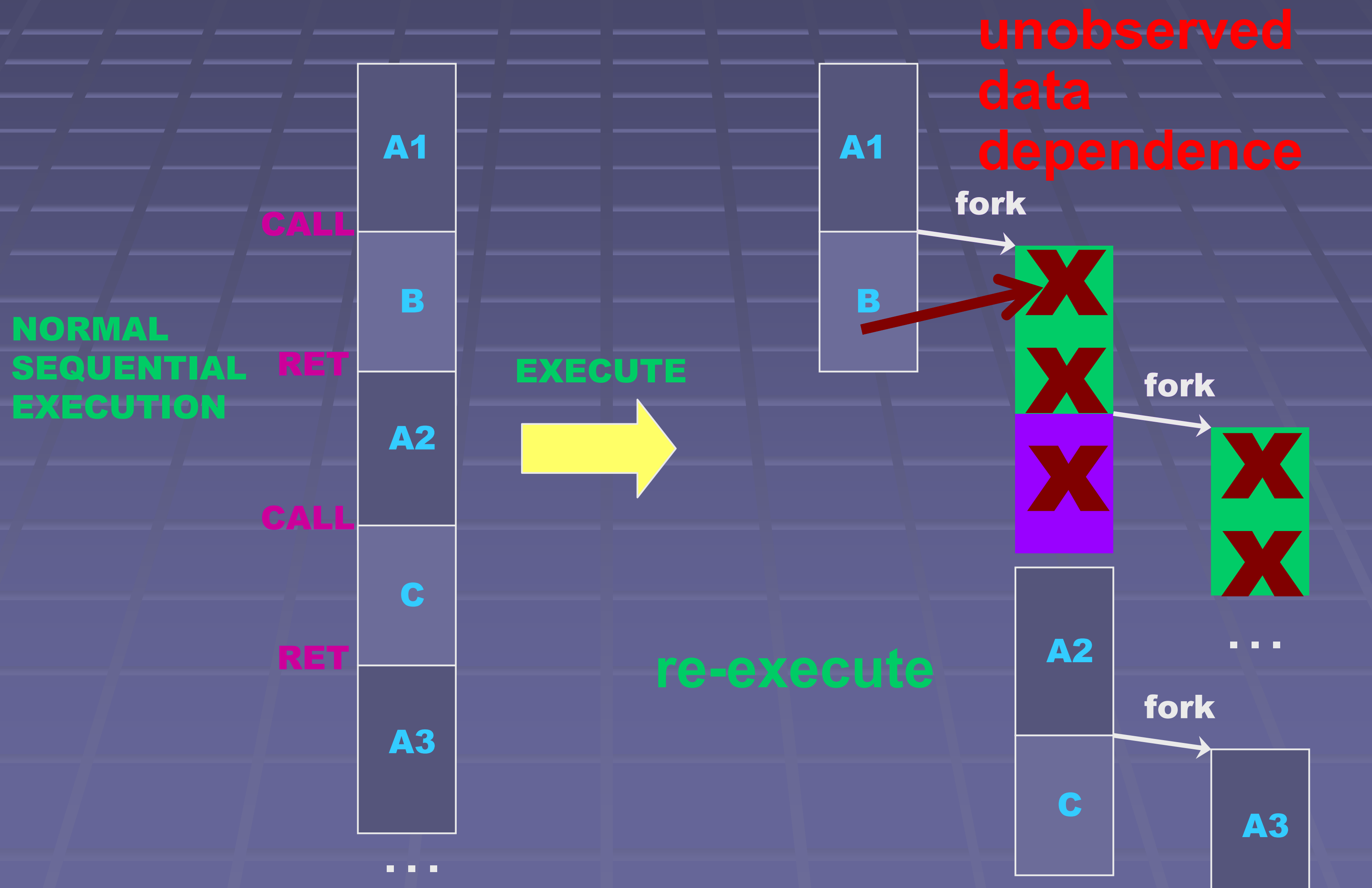
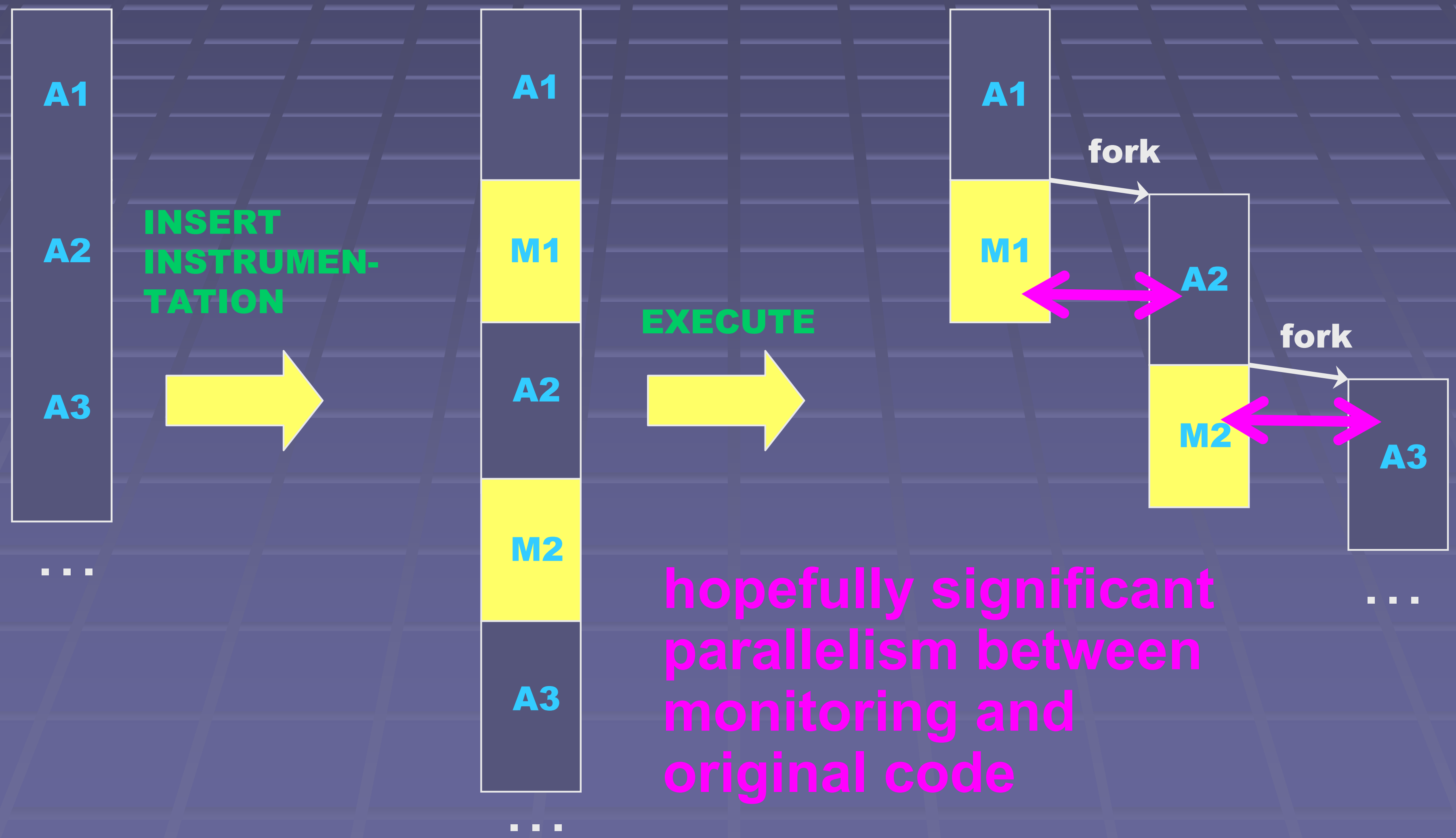
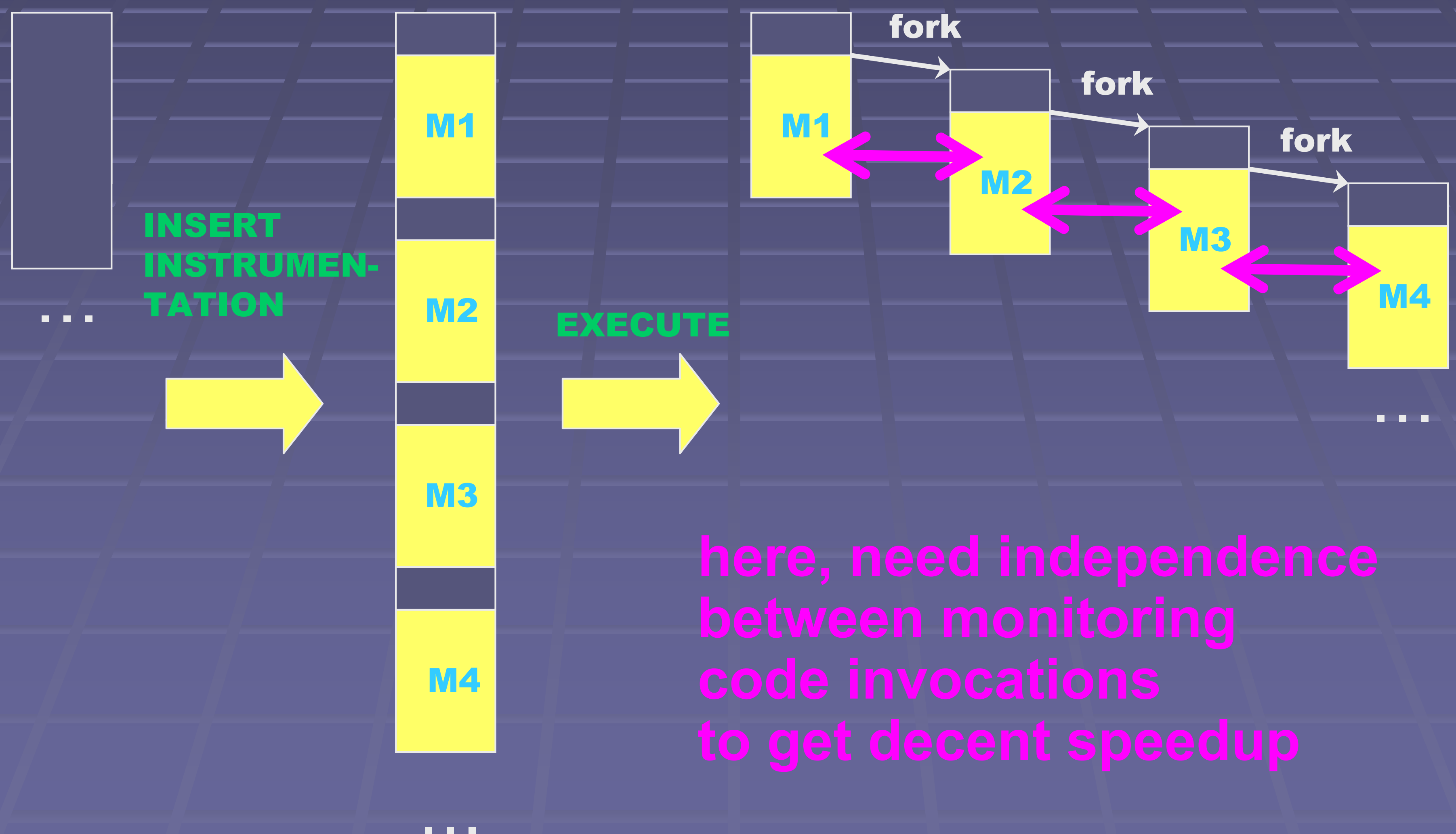


Using TLS to speed up Monitoring



hopefully significant parallelism between monitoring and original code

Using TLS to speed up Heavy Monitoring



here, need independence
between monitoring
code invocations
to get decent speedup

Future Directions

- Right now, performance not critical (or they'd be multithreading already!)
- As models to be verified get more complex…
- As verification programs get smarter…

Summary

- Largely memory bound
  - Ratio of memory to arithmetic operations is large
  - Little to no locality
    - Pre-fetching might be effective
- Good opportunities for exploiting TLP
- Currently, research on methods of reduction probably more important than exploiting hardware
- Complexity of verification systems will scale with growing complexity of systems to be analyzed