Improving Continuation-Powered Method-Level Speculation for JVM Applications

Ivo Anjo   João Cachopo

ESW
INESC-ID Lisboa/Instituto Superior Técnico/Universidade de Lisboa

December 2013

-8 days left in 2k13

...and still many applications are single-threaded

Hard to rewrite many existing applications to work in parallel

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↓

Automatic Parallelization

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Automatic Parallelization

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Analyze applications, run parts in parallel

Many Java/JVM applications are irregular

- Inheritance
- Polymorphism
- Encapsulation

... other OO features

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- Polymorphism
- Encapsulation

  ... other OO features

➜ Hard to analyze statically

Speculative Parallelization

- No need to statically prove that parallelization is valid
- Correctness dynamically ensured at runtime

After task identification, how to fully utilize a parallel machine?

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New techniques for improved resource

- *usage*
- *management*

In previous work we introduced **JaSPEx-MLS**...

JaSPEx-MLS

- Software-based speculative parallelization for Java

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- Software-based speculative parallelization for Java
- Bytecode rewriting

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- Bytecode rewriting

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- Handling non-transactional operations

- Method-Level Speculation
- Custom STM model
- Nested speculation

...on top of the OpenJDK Java VM + Continuation support

Method-Level Speculation

```
int example1() {
    int x = computeValue();
    int y = 0;
    for (...) y += ...;
    return x+y;
}
```

- Run method call in parallel with code following its return

Method-Level Speculation

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int example1() {
    int x = computeValue();
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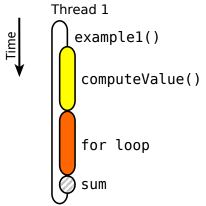

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Method-Level Speculation

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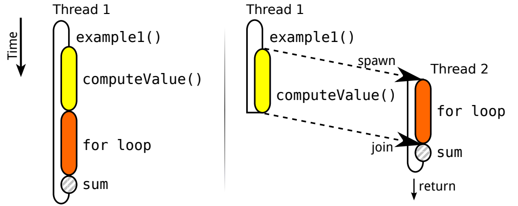
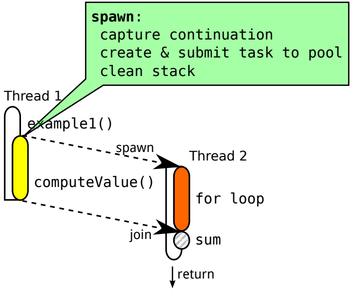


- Run method call in parallel with code following its return

What really happens behind the scenes

```
int example1() {
    Future x = spawn computeValue();
    int y = 0;
    for (...) y += ...;
    return x.get()+y;
}
```

What really happens behind the scenes



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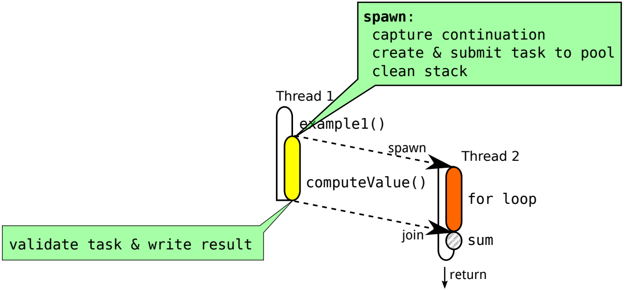

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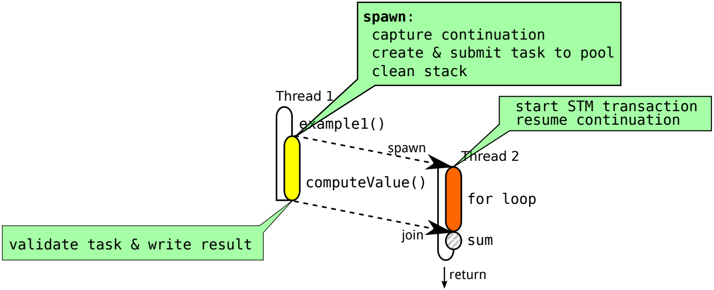

MLS spawn

- Existing task – **method call**:
  - ➔ Keeps executing in the same thread
- New task – **code following method call**:
  - ➔ Submitted to the thread pool

    ...if there are free threads

New task

- Starts executing

  ...until
- Needs value from other unfinished task
- Needs to execute non-transactional operation
- Ready to commit, but parent still working

New task

- Starts executing

  ...until

- Needs value from other unfinished task
  - ➔ Wait for other task
- Needs to execute non-transactional operation

- Ready to commit, but parent still working

New task

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  ...until

- Needs value from other unfinished task
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New task

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  ...until
- Needs value from other unfinished task
  - → Wait for other task
- Needs to execute non-transactional operation
  - → Wait for program-order
- Ready to commit, but parent still working
  - → Wait for parent task

Improving MLS (aka outline):

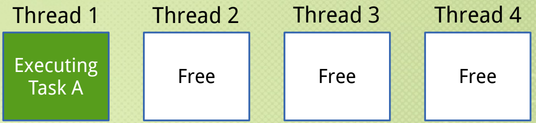
- Task buffering
- Task freezing
- STM-assisted return value prediction
- Captured memory

➜ Remove waiting, allow more tasks

Thread Pool

Original Design:
Limited number of threads + Direct hand-offs

Thread Pool – Underusage



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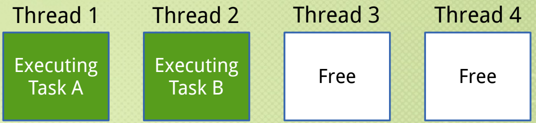

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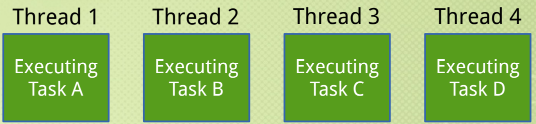

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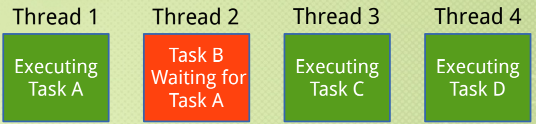

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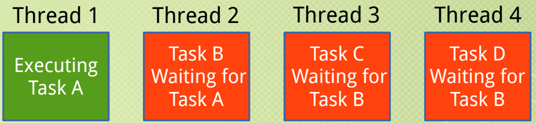

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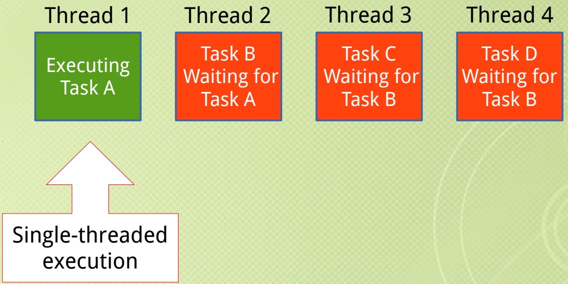
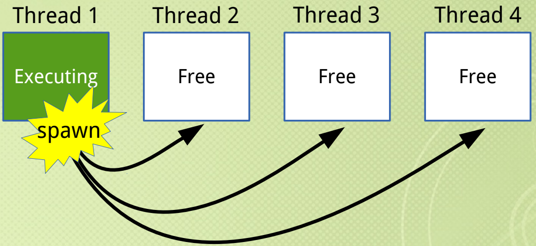


Another issue...

Thread Pool – Underusage II



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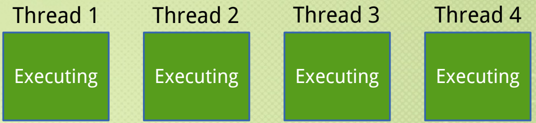

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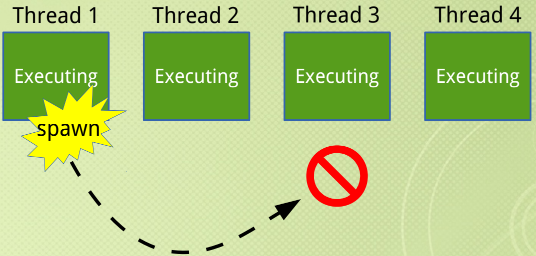

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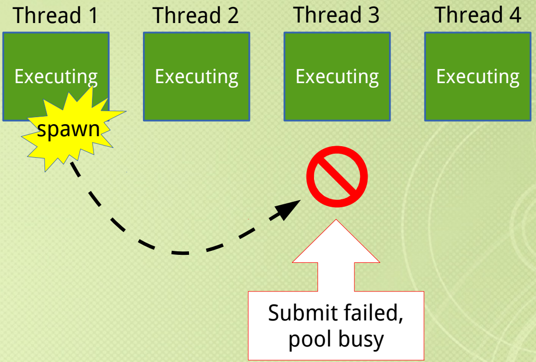

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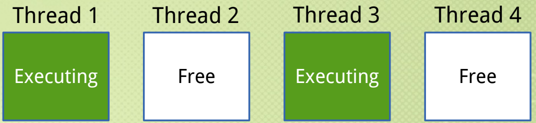

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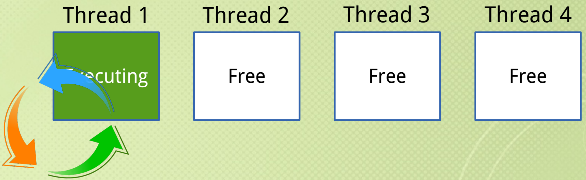

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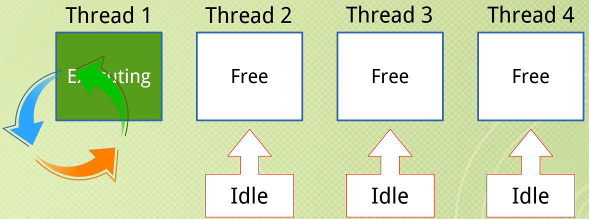

Thread Pool Issues

- # Program Threads > # Hardware Threads?
  - Lots of context switching overheads
    - *...especially if they are actually working and not just waiting*

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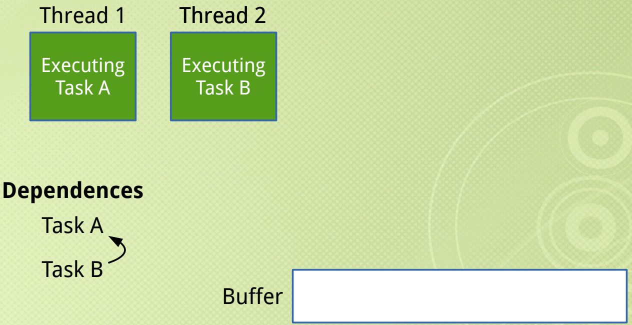
- What about buffering?

Thread Pool – Naive Buffering



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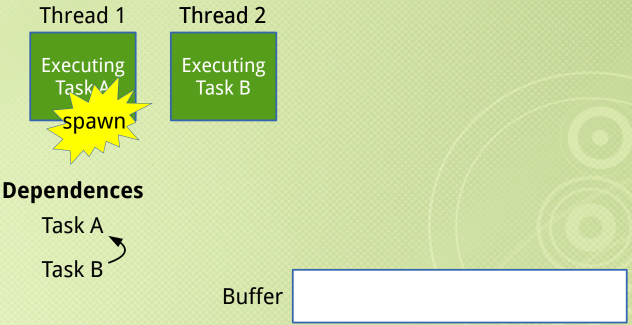

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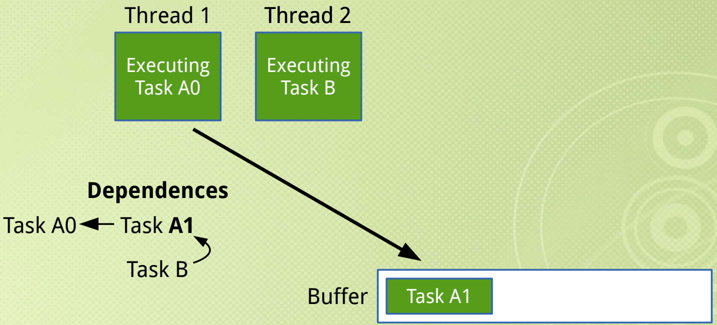

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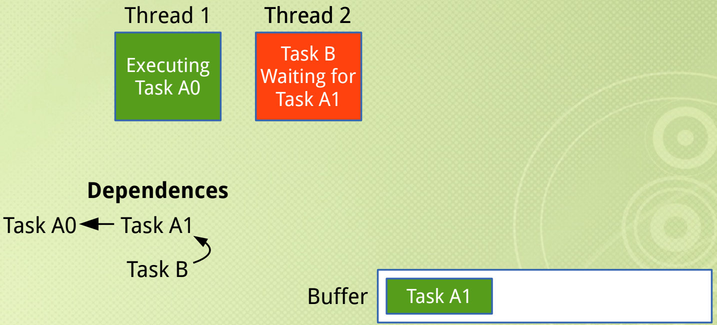

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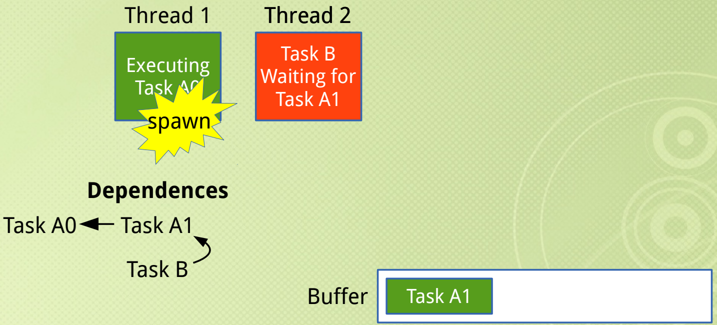

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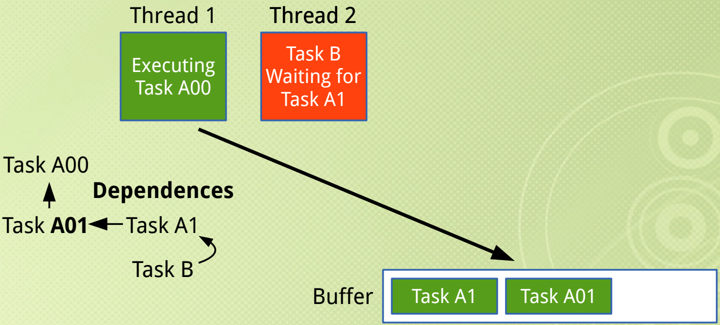

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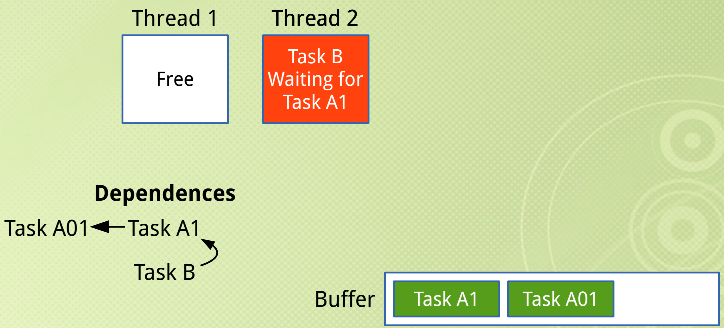

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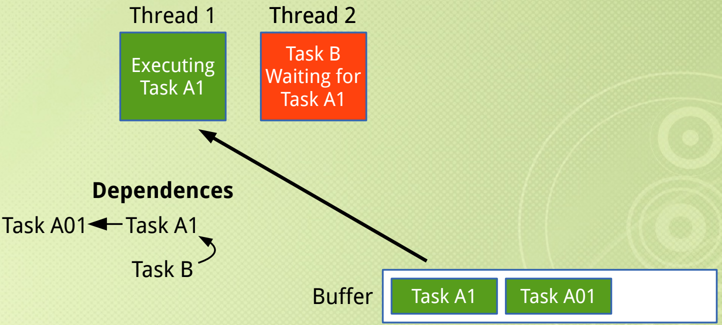

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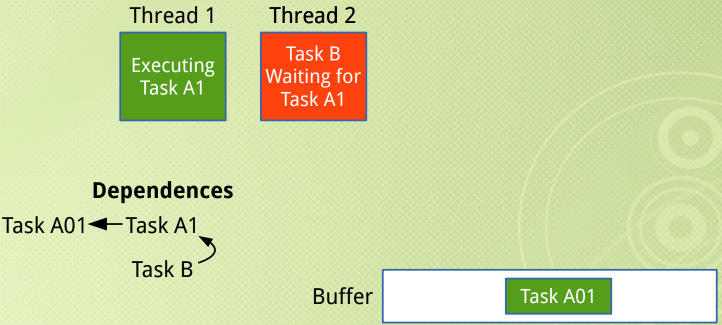

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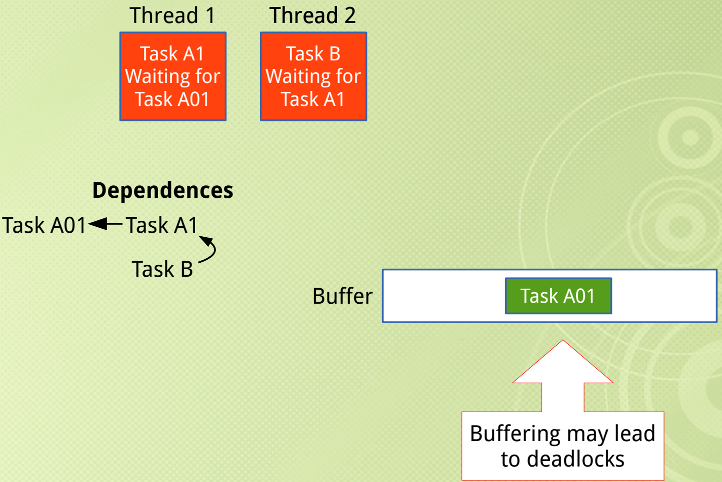


Hybrid Thread Pool Queue

- Try to combine advantages from buffering
  - More efficient handoffs
  - Better resource utilization

  ...while still preserving correctness

Hybrid Thread Pool Queue

- Augment pool with deadlock detector
  - Detects when all threads are waiting simultaneously
- Buffer tasks by default, fallback to direct hand-offs when issue detected
- Preserves correctness
  - Deadlocks are very rare (workload-specific)
  - Better performance in the normal case

Previously...

MLS spawn

- Existing task – **method call**:
  - ➔ Keeps executing in the same thread
- New task – **code following method call**:
  - ➔ Submitted to the thread pool

    ...if there are free threads

Now...

MLS spawn

- Existing task – **method call**:
  - ➔ Keeps executing in the same thread
- New task – **code following method call**:
  - ➔ Submitted to the thread pool

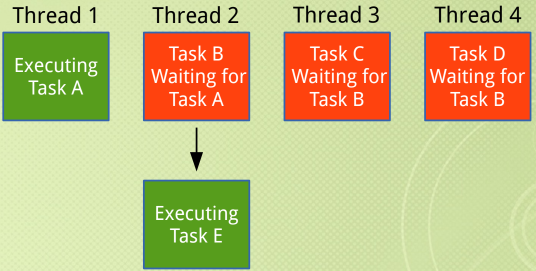
    ...if there a [illegible] *ads*

BUFFER

Going back to the waiting part...

Reuse threads?

Going back to the waiting part...



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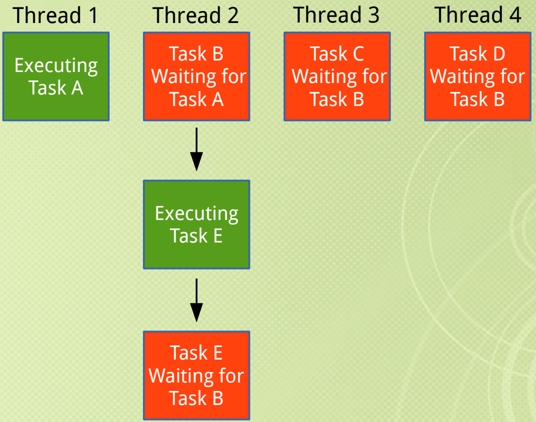

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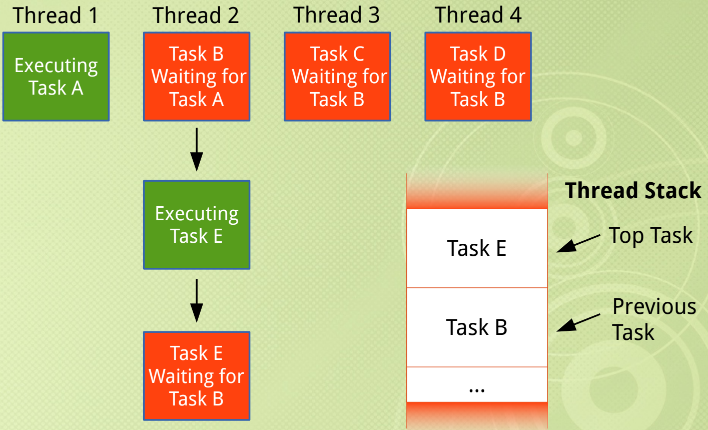

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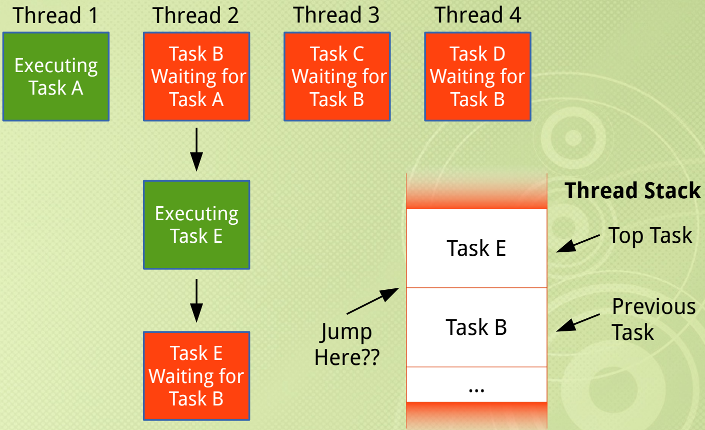
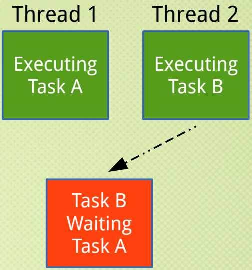


Task Freeze

Idea:

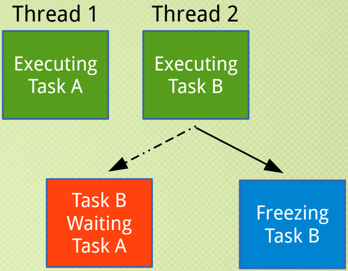
- Use JVM with continuation support to save and transfer task state

Task Freeze

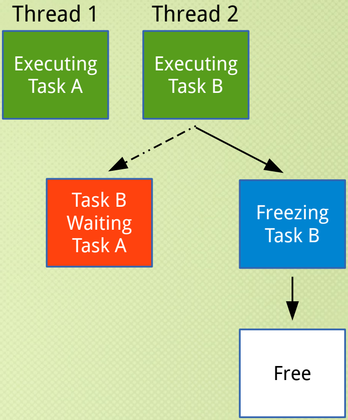


Thread 1
Thread 2
Executing Task A
Executing Task B
Task B Waiting Task A

Task Freeze

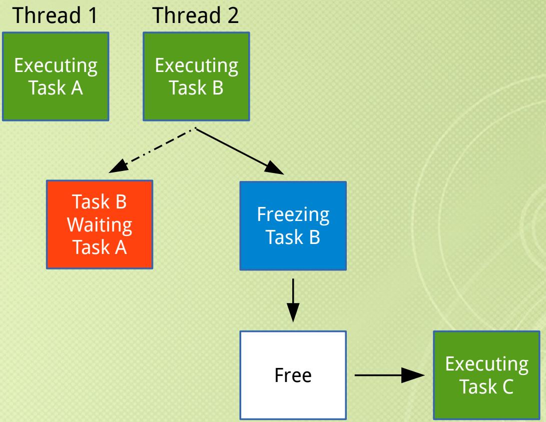

Thread 1
Thread 2
Executing Task A
Executing Task B
Task B Waiting Task A
Freezing Task B

Task Freeze

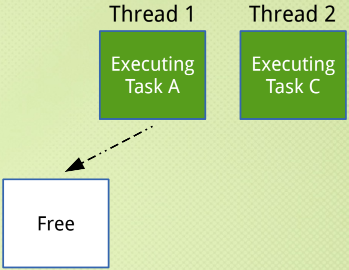


Thread 1
Thread 2
Executing Task A
Executing Task B
Task B Waiting Task A
Freezing Task B
Free

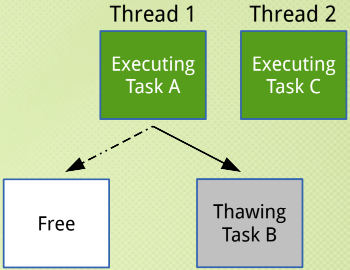
Task Freeze


Thread 1
Thread 2
Executing Task A
Executing Task B
Task B Waiting Task A
Freezing Task B
Free
Executing Task C

Task Freeze

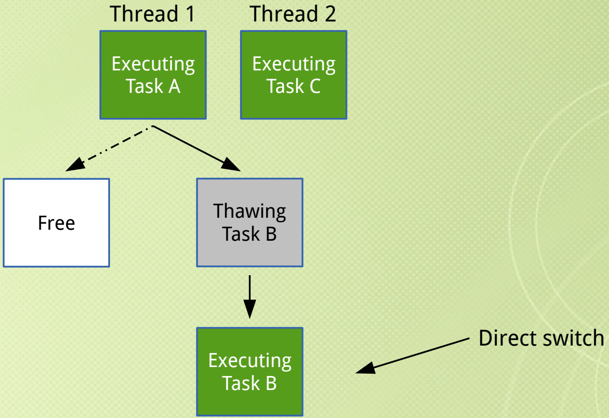


Task Freeze



Thread 1
Thread 2
Executing Task A
Executing Task C
Free
Thawing Task B

Task Freeze


Thread 1
Thread 2
Executing Task A
Executing Task C
Free
Thawing Task B
Executing Task B
Direct switch

Improved Runtime Model

New task

- Starts executing

  ...until

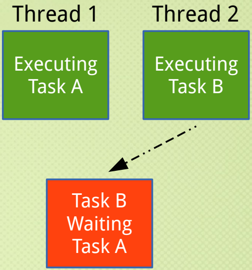
- Needs value from other unfinished task
  - Wai FREEZE ask
- Needs to execute non-transactional operation
  - Wai FREEZE n-order
- Ready to commit, but parent still working
  - Wai f FREEZE task

Return Value Prediction

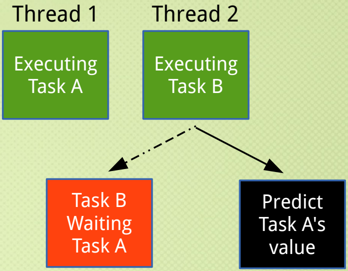
Idea:

- Instead of waiting, guess the value needed

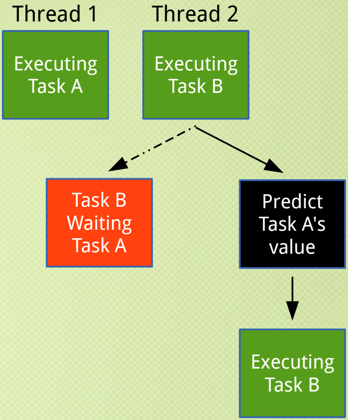
Return Value Prediction



Return Value Prediction



Return Value Prediction



Return Value Prediction

Our idea:

- STM-assisted RVP
  - Use STM to register prediction in the **read-set**
  - Use STM to validate prediction
    - Validated during transaction commit

Return Value Prediction

- STM-assisted RVP
  - Supports obtaining multiple predictions (from multiple other tasks)
  - Pluggable predictor framework

Improved Runtime Model II

New task

- Starts executing

  ...until

- Needs value from other unfinished task
  - → Wai FREEZE as PREDICT
- Needs to execute non-transactional operation
  - → Wai FREEZE n-order
- Ready to commit, but parent still working
  - → Wai FREEZE task

Captured Memory

- Memory allocated cannot escape its allocating transaction
  - ➜ Objects are transaction-local until commit

Captured Memory

- If objects are transaction-local, we can access them directly

  → **No STM overhead**

Captured Memory in MLS

Issue:

- Objects may escape their allocating transactions under MLS

```
void example2() {
    A a = new A();                     Task A
    spawn computeValue();

    a.field = 10;                      Task B
    …
}
```

➔ No such thing as captured memory in our model?

Captured Memory in MLS

- But, looking at the original sequential program order

Dependences

Task A

Task B

- Objects may only escape to tasks **more speculative** than the ones that allocated them

Captured Memory in MLS

Solution

- Access objects in captured memory directly
- **More speculative** tasks still use STM to access the objects

Captured Memory: Further Advantages

```
void example3() {
    A a = new A();
    a.i++;                                   Task A
    spawn computeValue();

    a.i--;                                   Task B
    …
}
```

Task B would always abort

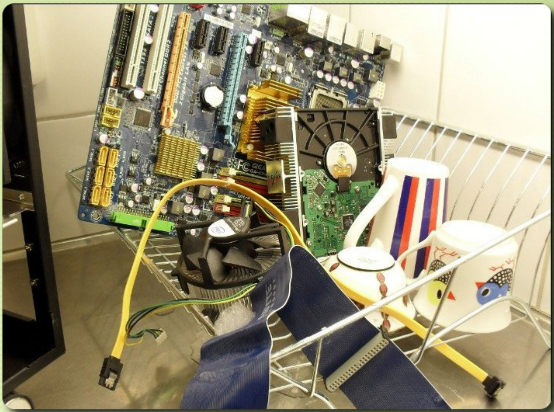
Captured Memory: Further Advantages

```
void example3() {
    A a = new A();
    a.i++;                          Task A
    spawn computeValue();

    a.i--;                          Task B
    …
}
```

Task B would always abort

➔ Captured memory is very beneficial to the MLS model

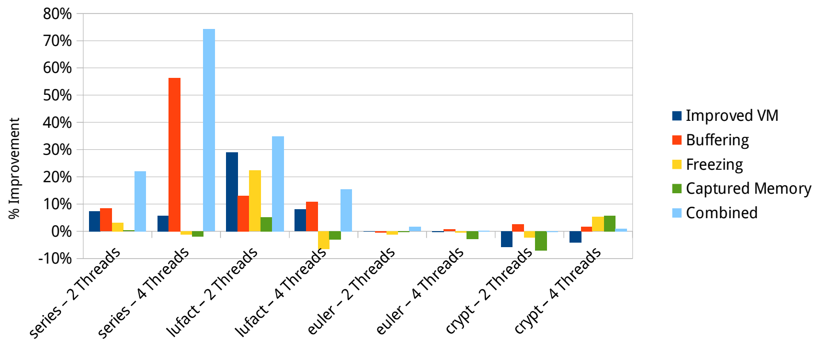


Benchmarks

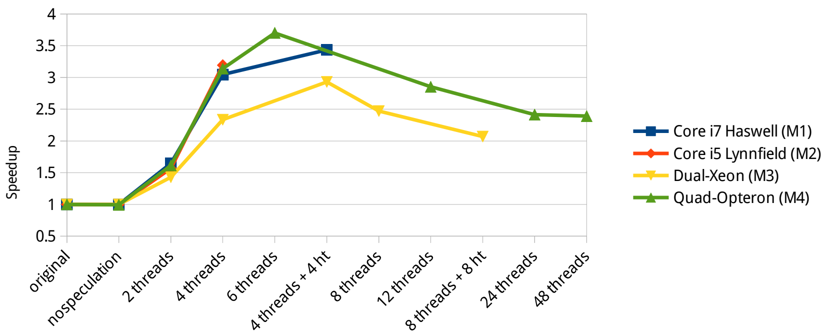
- **M1**: Intel Core i7 *Haswell* 4770 / 16GB
  - 4 cores + ht: 8 hw threads
- **M2**: Intel Core i5 *Lynnfield* 750 / 8GB
  - 4 cores: 4 hw threads
- **M3**: Intel Xeon *Nehalem* E5520 (dual-socket) / 24GB
  - 8 cores + ht: 16 hw threads
- **M4**: AMD Opteron *Magny-Cours* 6168 (quad-socket) / 128GB
  - 48 cores: 48 hw threads

- 64-bit Ubuntu / CentOS

- Java Grande Forum benchmark suite
- No code modifications applied

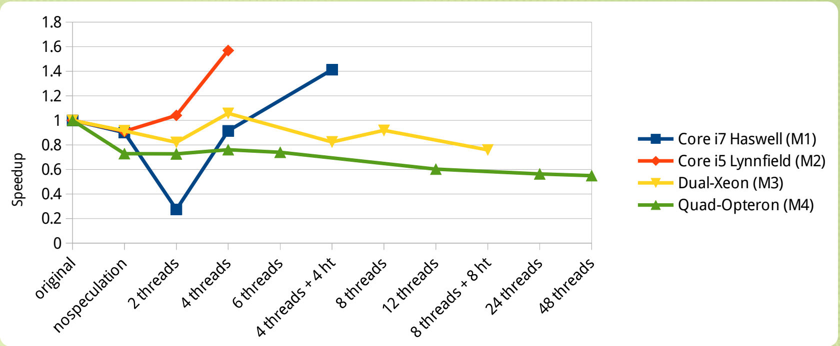


- Improvement of each new extension + their combined usage
- New features work together
  - Freezing can cause slowdown when used without buffering
  - Improved VM speeds up old code and new extensions



- Absolute speedup in the `series` benchmark

- Barnes-Hut from the Lonestar Benchmark Suite
- No code modifications applied



- Bigger bytecode transformations overhead than series
  - 10% for M1-M3
  - 30% for M4

- Buffering disabled for M1 due to bug

Conclusions

- Speculative parallelization is a viable approach for irregular JVM applications
- Presented several techniques that work together to enhance MLS
  - Task buffering via hybrid thread pool queue
  - Task freezing
  - STM-assisted Return Value Prediction
  - Captured memory
- Benchmarks from implemented techniques in JaSPEx-MLS yield speedups for unmodified applications on real hardware on a production-ready JVM

Thank you!