Transactional Memory Support for Scalable and Transparent Parallelization of Multiplayer Games

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Multiplayer games

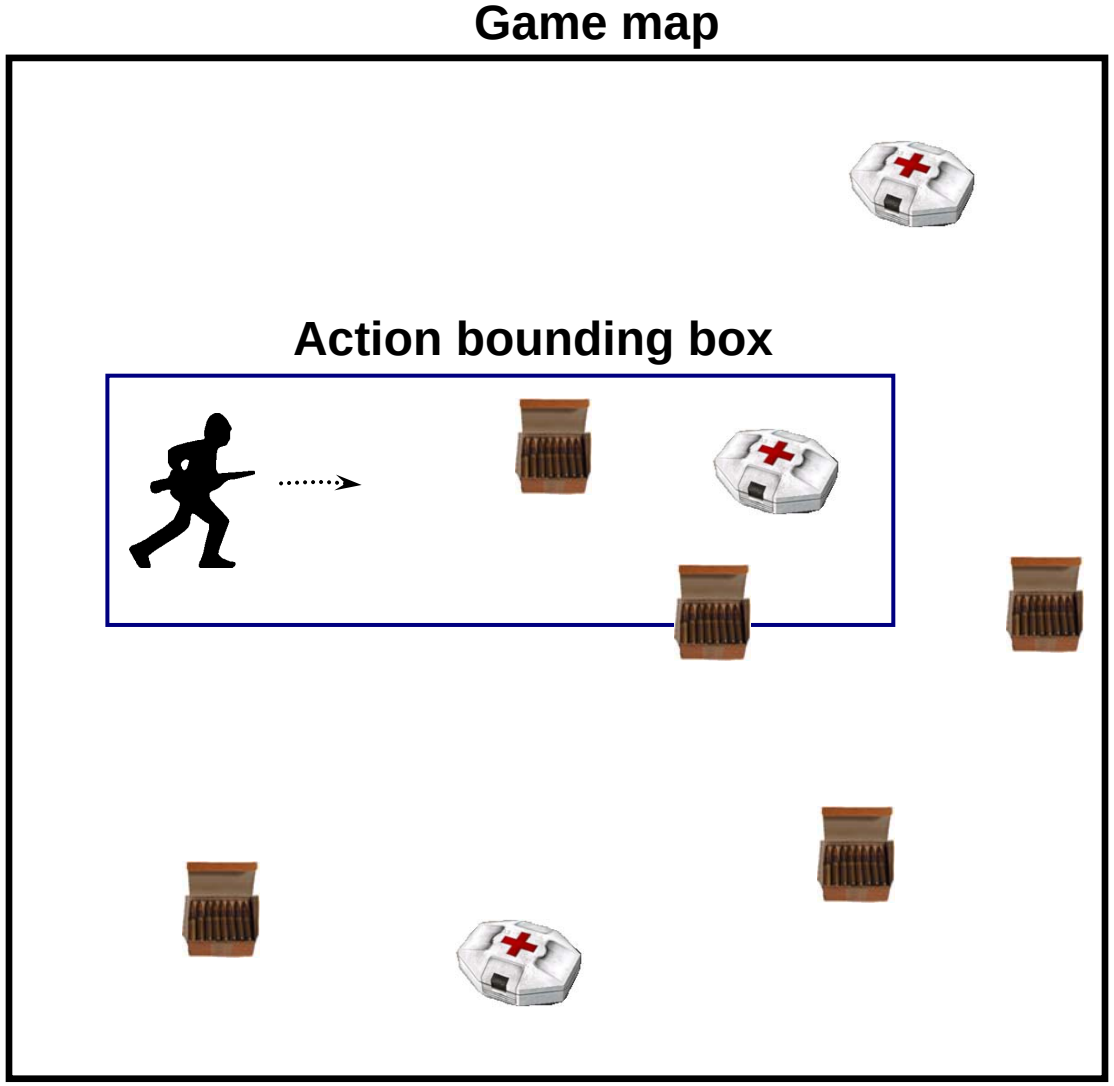
- More than 100k concurrent players

Game server is the bottleneck

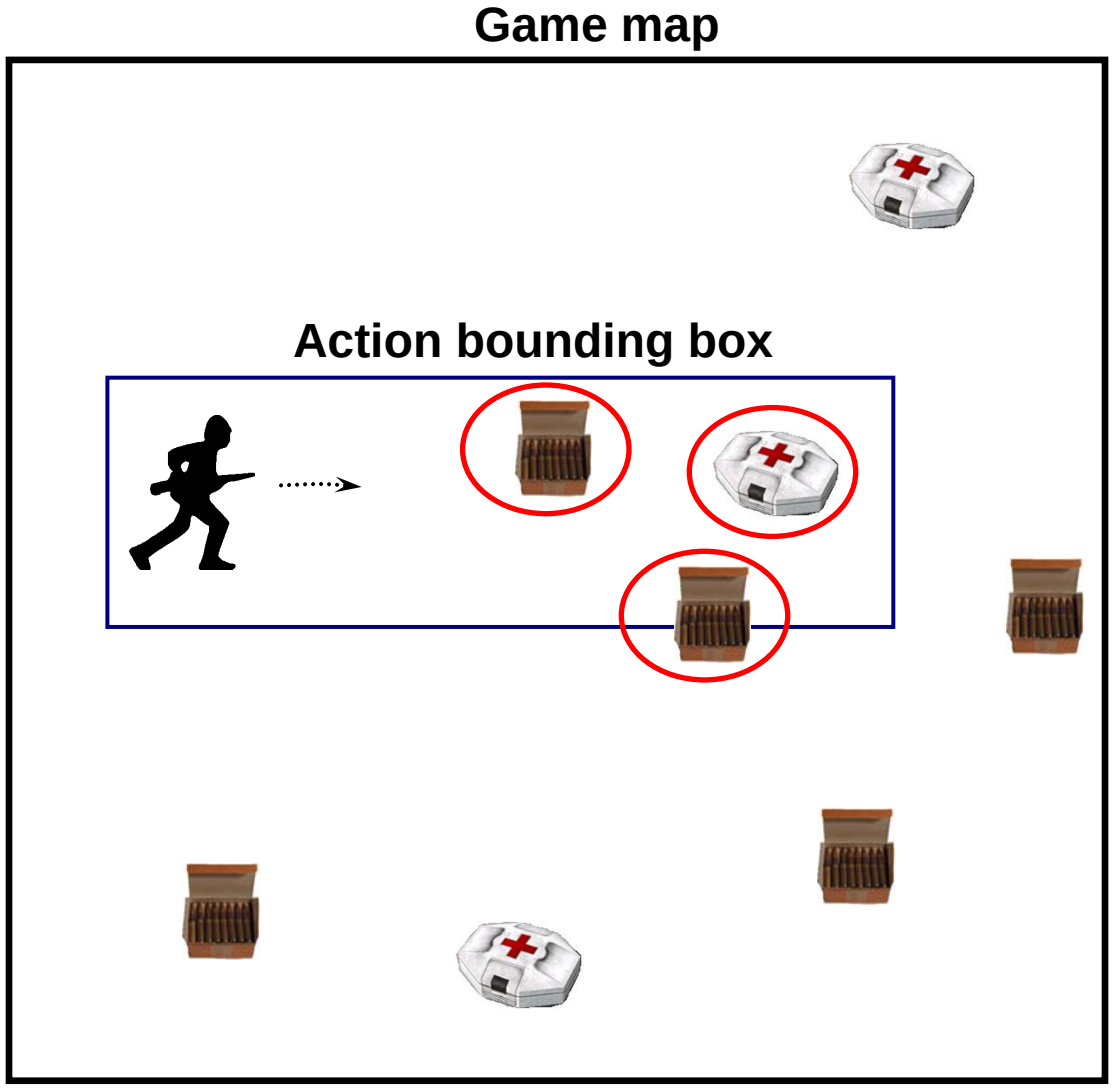
State-of-the-art

- Previous parallelizations of Quake
  - Lock-based [Abdelkhalek et. al ‘04] shows that false sharing is a challenge
  - Zyulkyarov et. al ’09
  - Gajinov et. al ’09

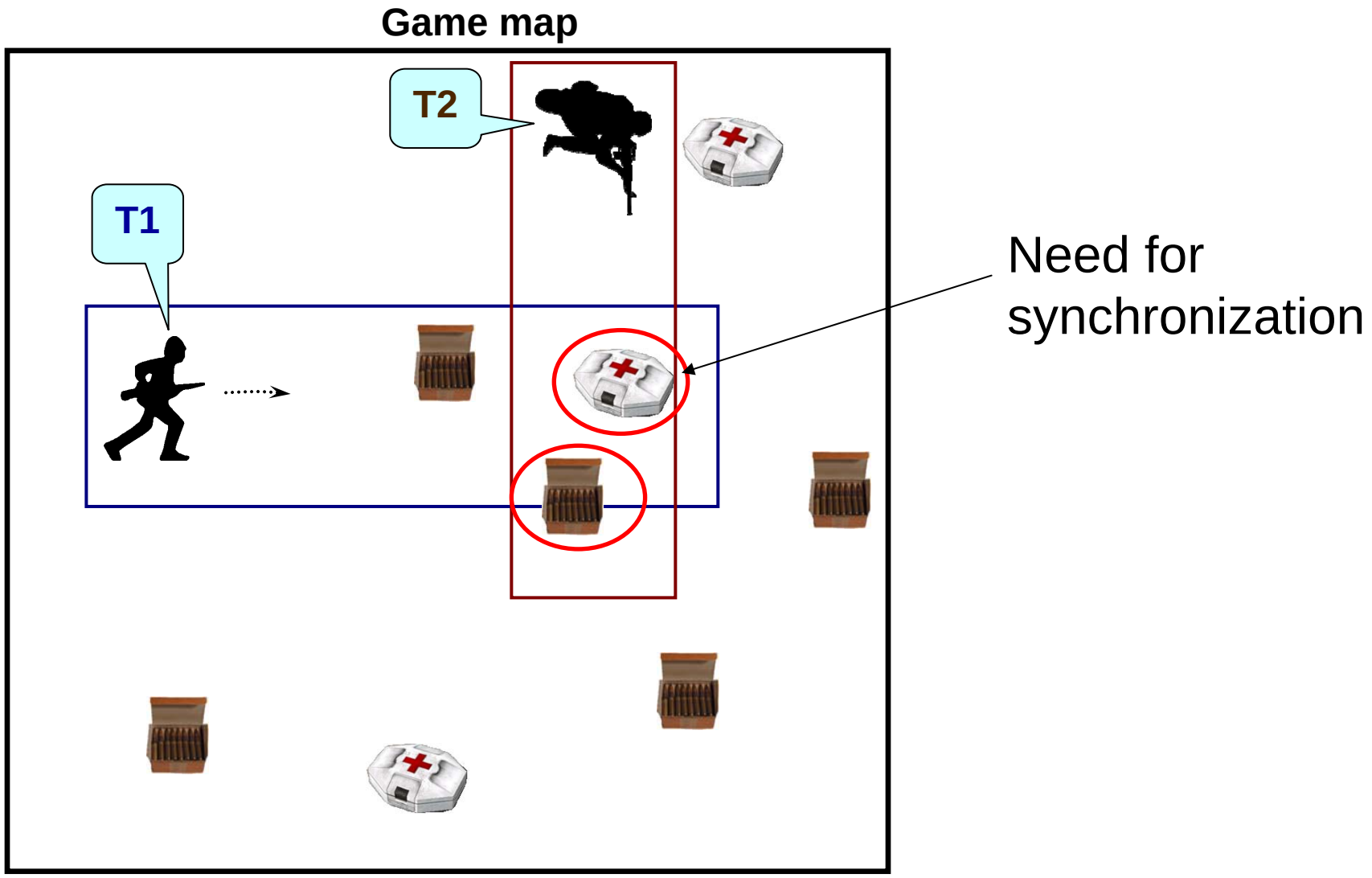
Game interactions



Collision detection



Conflicting player actions

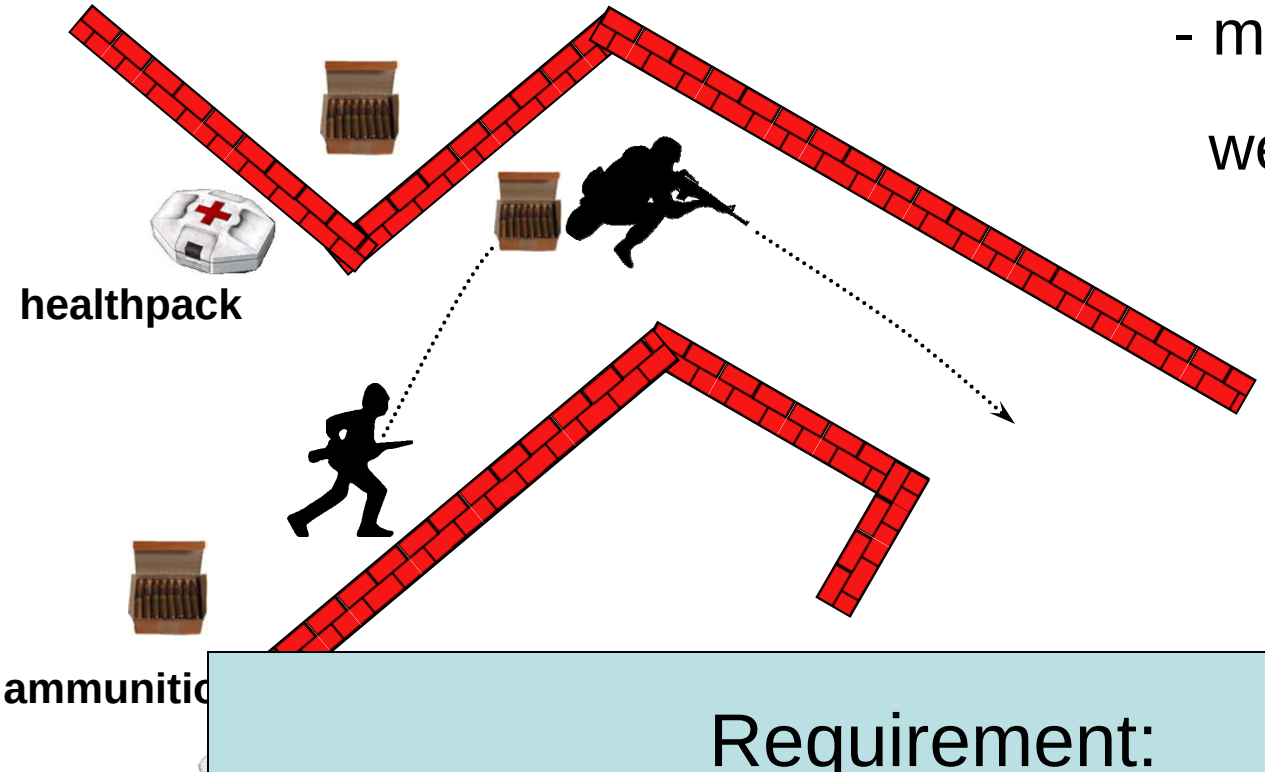


Player actions

Compound action:

- move, charge

weapon and shoot



Requirement:
consistency and atomicity
of whole game action

Conservative locking

GAME ACTION

Lock 1, Lock 2, Lock3

Subaction 1

Subaction 2

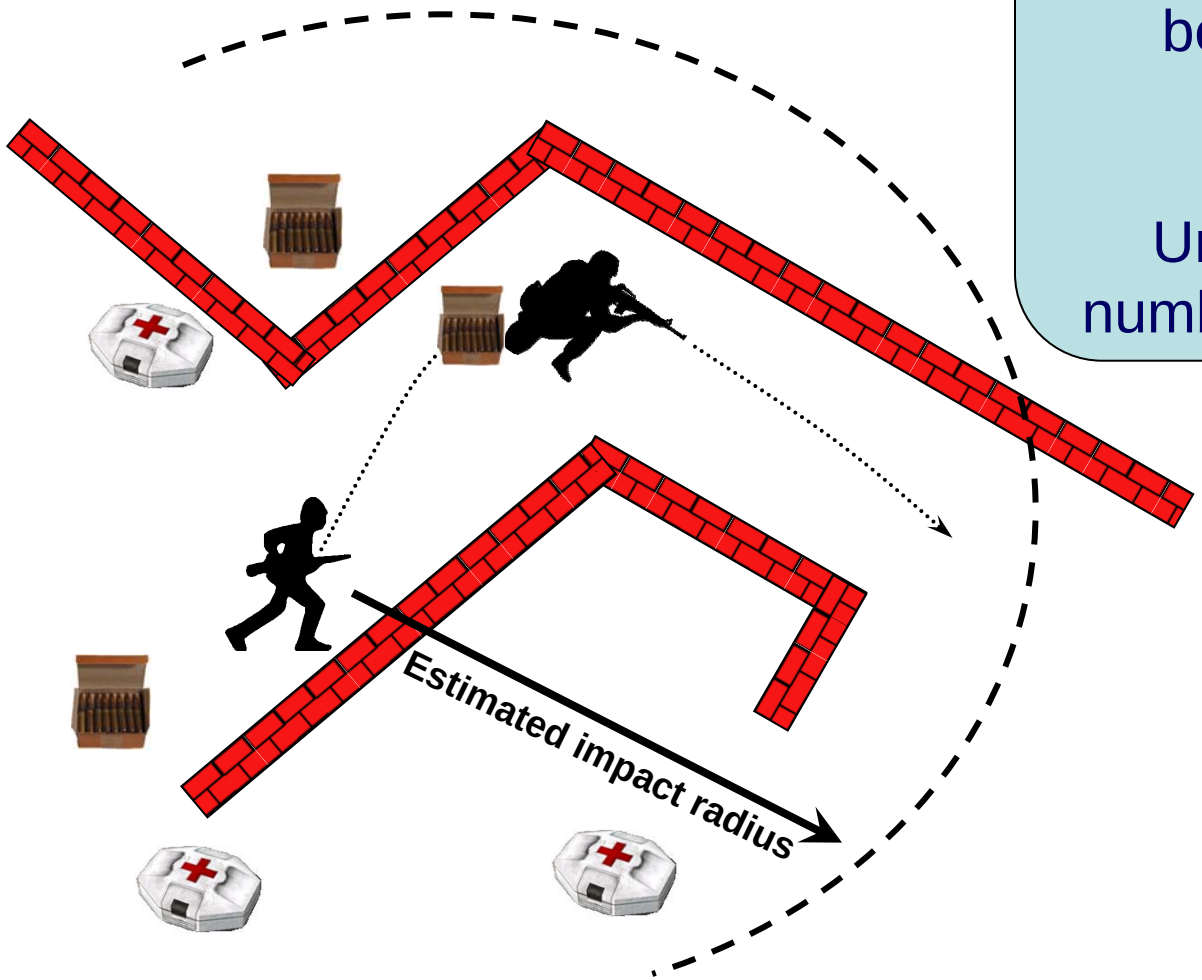
Subaction 3

Unlock 1,2,3

Conservatively acquire all locks at beginning of action

Problem 1:
Unnecessarily long conflict duration

Conservative locking



Conservative estimate of impact range at beginning of action

Problem 2:
Unnecessarily high number of locked objects

Fine-grained locking alternative?

GAME ACTION

- Lock 1
- Subaction 1
- Unlock 1
- Lock 2
- Subaction 2
- Unlock 2
- Lock 3
- Subaction 3
- Unlock 3

Not possible !

Problem:
- No atomicity for whole action

Fine-grained locking alternative?

GAME ACTION

- Lock 1
- Subaction 1
- Lock 2
- Subaction 2
- Lock 3
- Subaction 3
- Unlock 1, 2, 3

Not possible !

Problem:
- Deadlocks

Software Transactional Memory

- Alternative parallelization paradigm
  - Implement game actions as transactions
  - Track accesses to shared and private data
  - Conflict detection and resolution

- Automatic *consistency and atomicity*
  - Transaction commits if no conflict
  - Transaction rolls back if conflict occurs

STM - Synchronization

GAME ACTION

BEGIN Transaction

Subaction 1

Subaction 2

Subaction 3

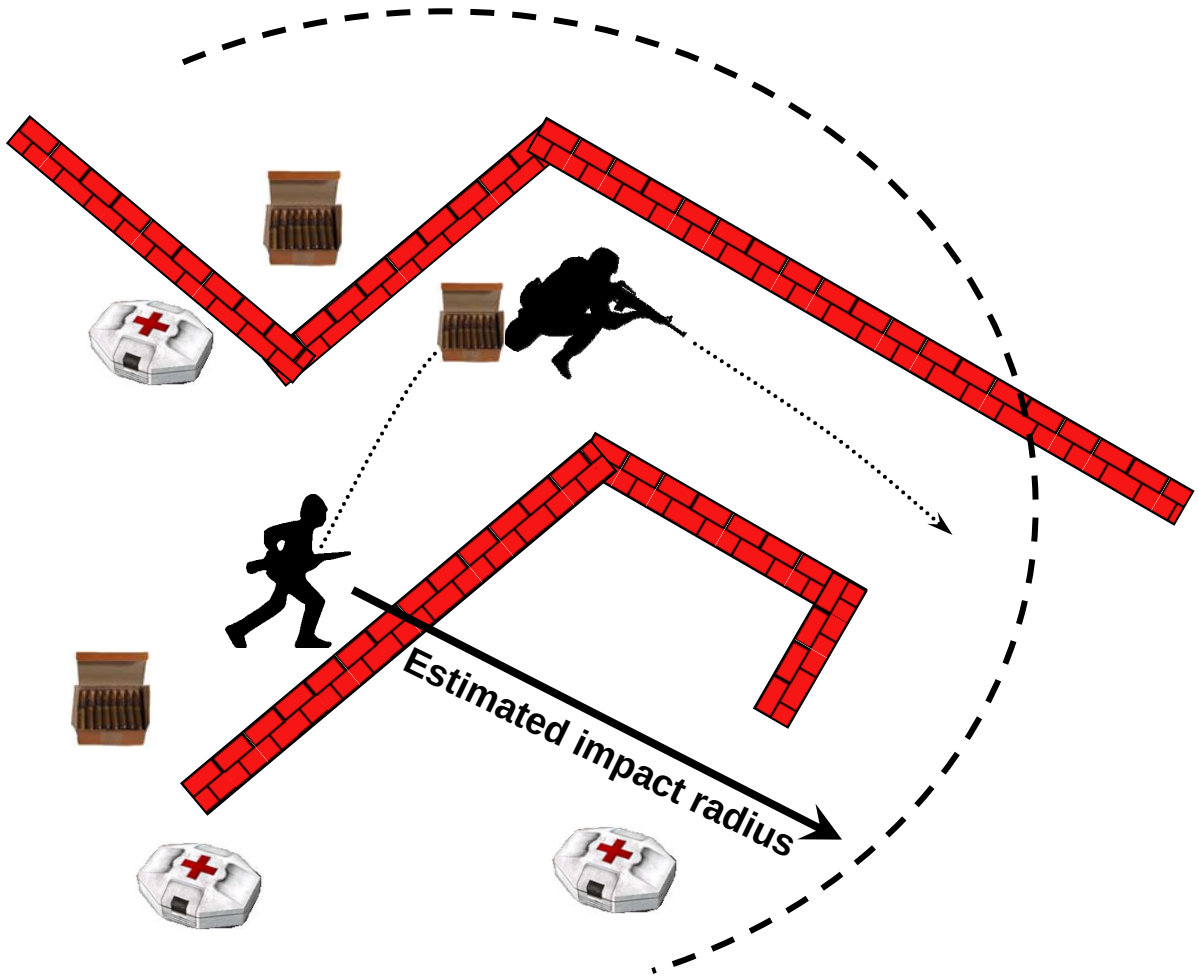
COMMIT Transaction

Problems solved:

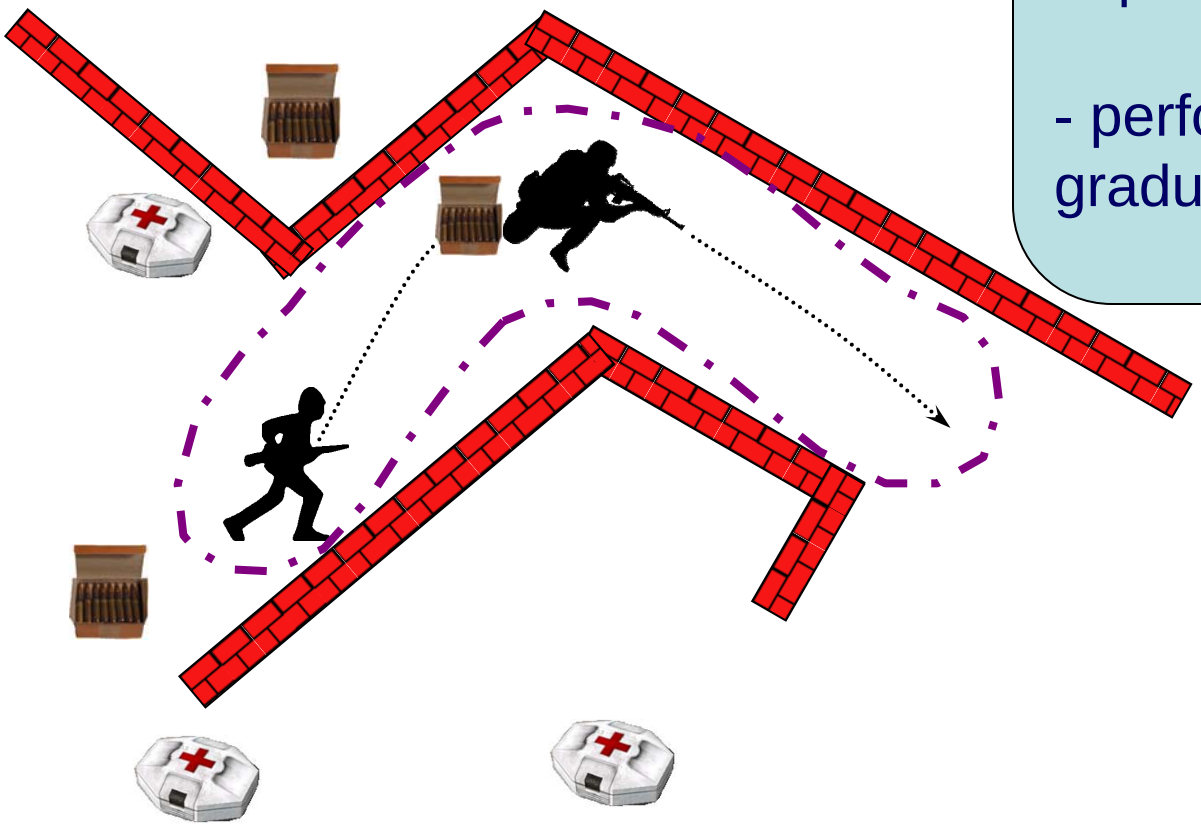
- Deadlocks
- Atomicity

Handled automatically

STM - Synchronization



STM - Synchronization



Collision detection optimized:

- split action into subactions

- perform collision detection gradually for each subaction

Transactional Memory vs. Locks

- Advantages of STM
  - Simpler programming task
  - Transparently ensures correct execution (deadlock problems and atomicity)
- Disadvantages
  - Software (STM) access tracking overheads

Never before shown to be competitive with lock synchronization for real applications

Contributions

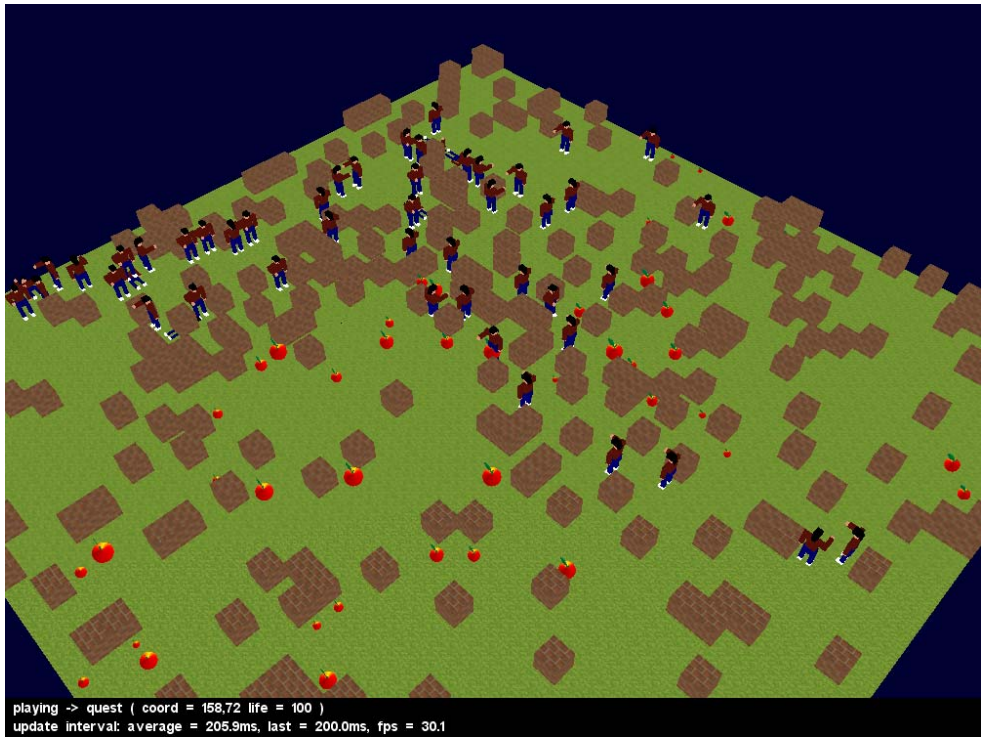
- Case study of parallelization for games
  - synthetic version of Quake (SynQuake)
- We compare 2 approaches:
  - lock-based and STM parallelization
- We showcase the first application where **STM outperforms locks ☺**

Outline

- Application environment: SynQuake game
  - Data structures, server architecture
- Parallelization issues
  - False sharing
  - Load balancing (true sharing)
- Experimental results

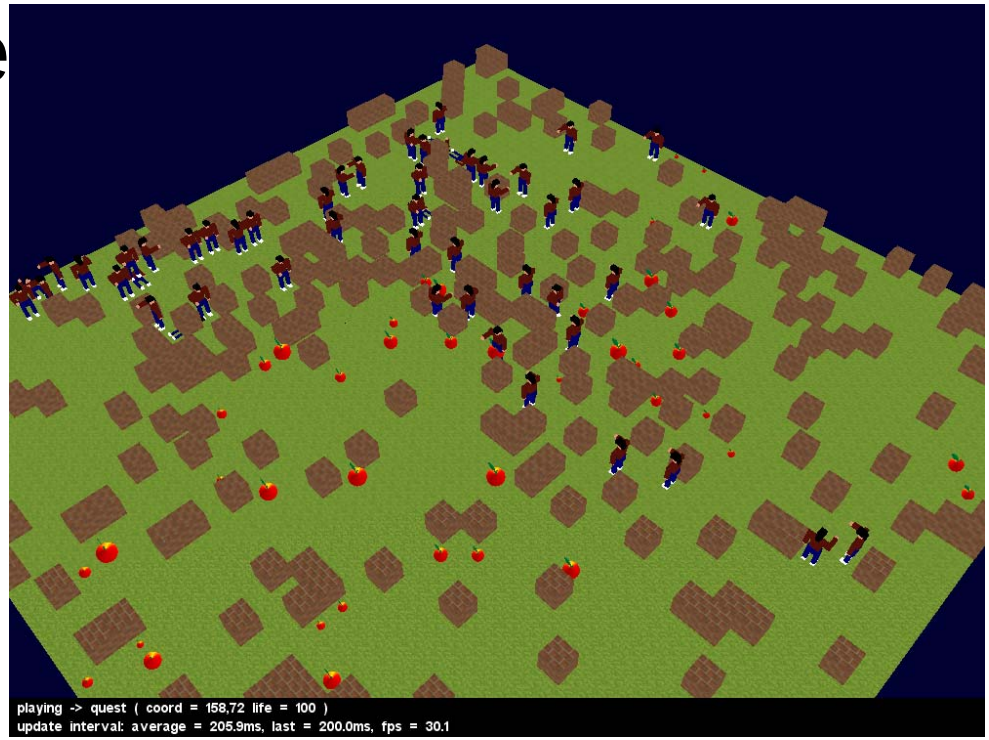
Environment: SynQuake game

- Same as Quake:
  - Gameplay
    - entities
    - interactions
  - Data structures
  - Server design



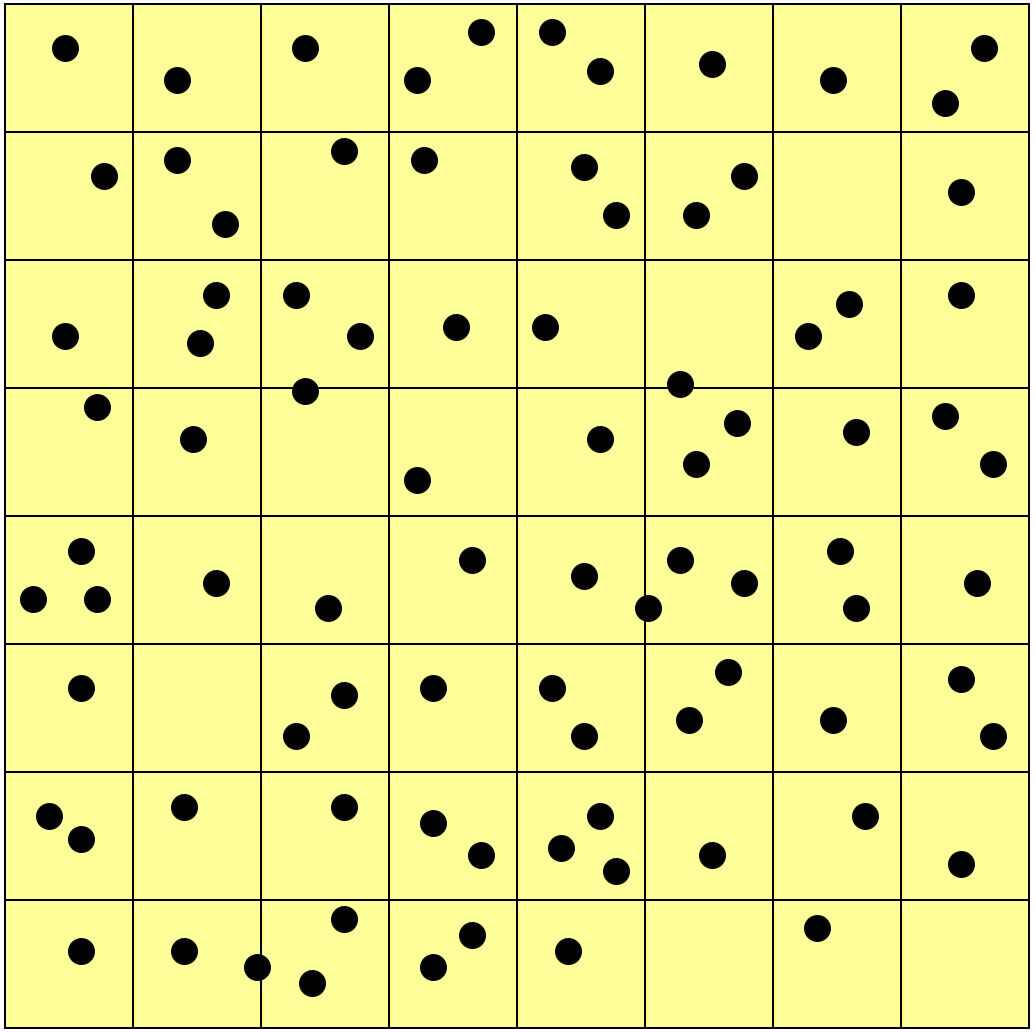
Environment: SynQuake game

- Different from Quake
  - 2D maps
  - World physics
- Facilitates workload generation
  - Game map
  - Bots
  - Quests

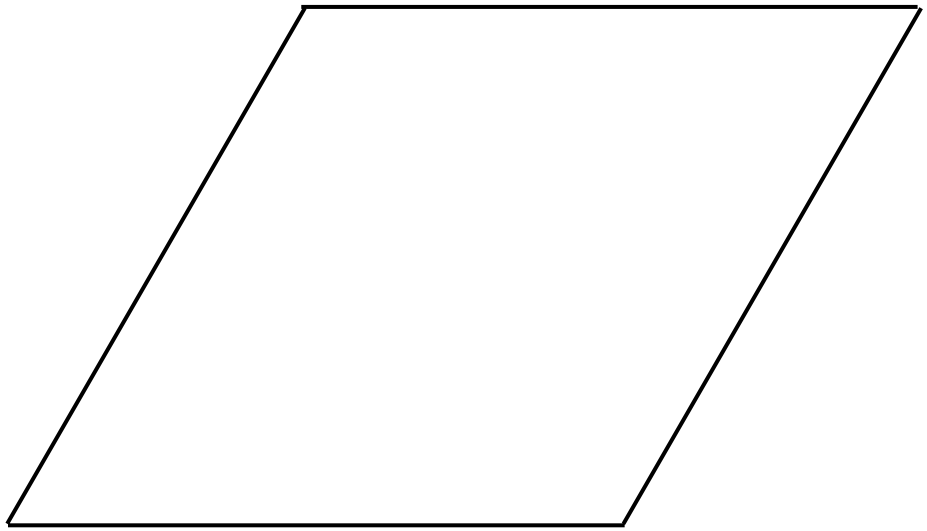


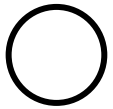
Game map representation

- Fast retrieval of game objects
- Quake spatial data structure: **Areanode Tree**



Areanode tree



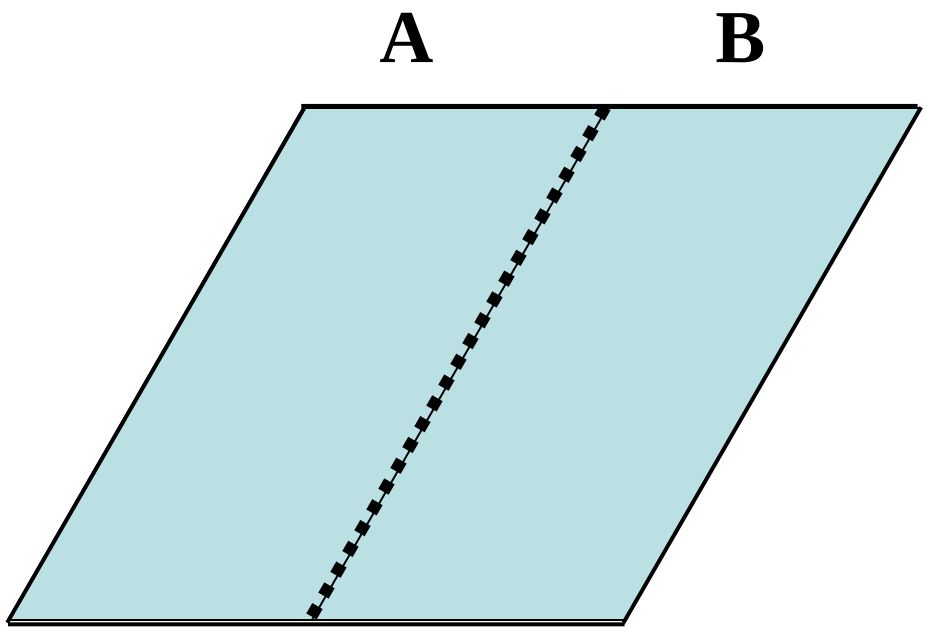


Root node

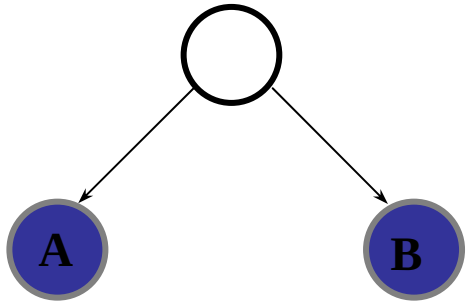
Game map

Areanode tree

Areanode tree

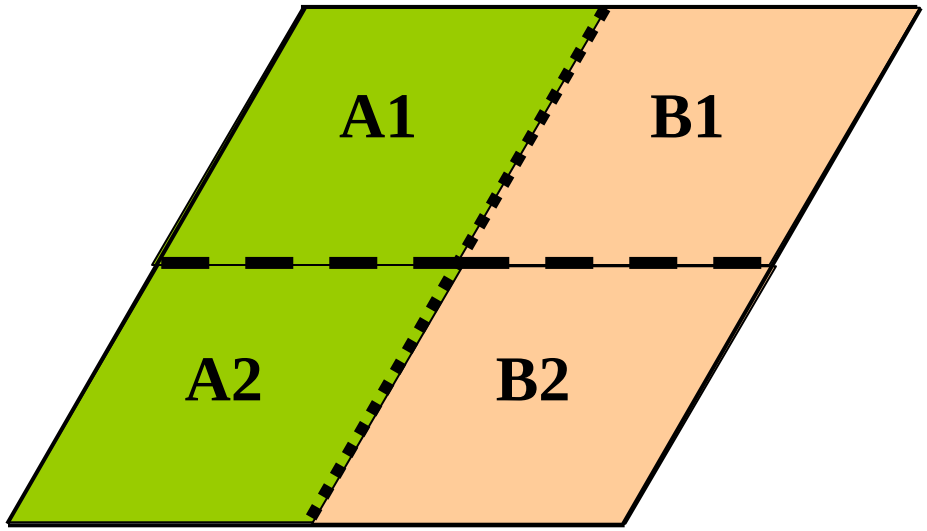


Game map

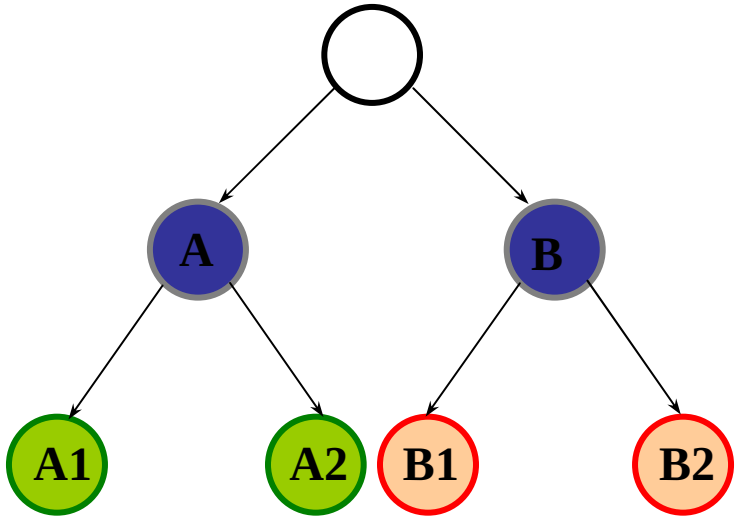


Areanode tree

Areanode tree

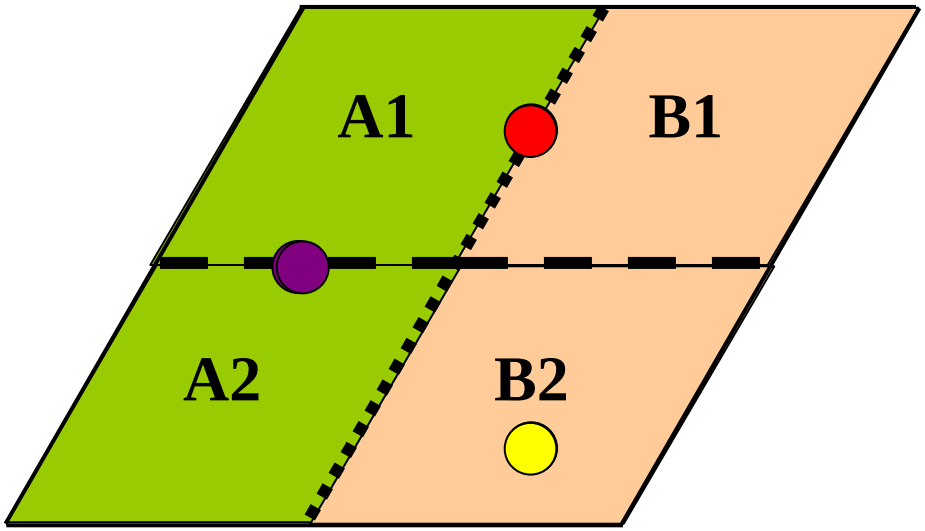


Game map

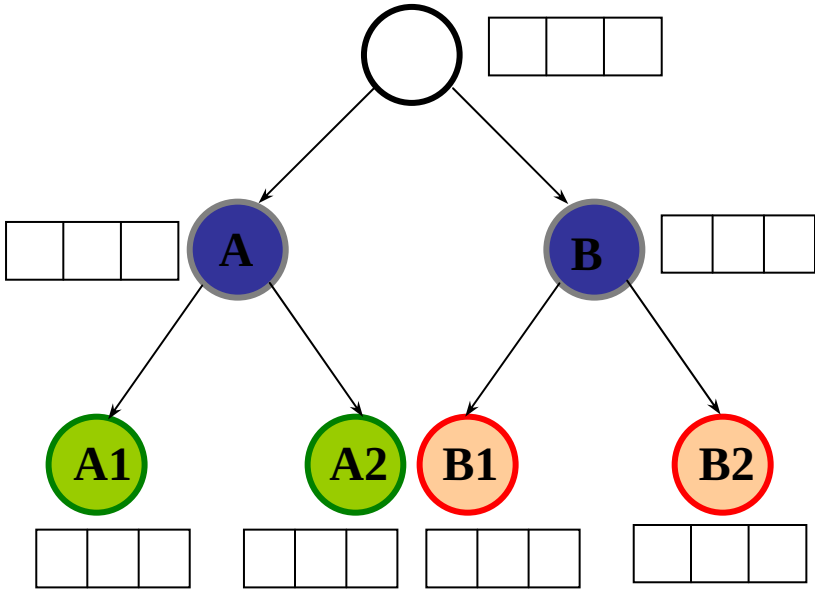


Areanode tree

Areanode tree

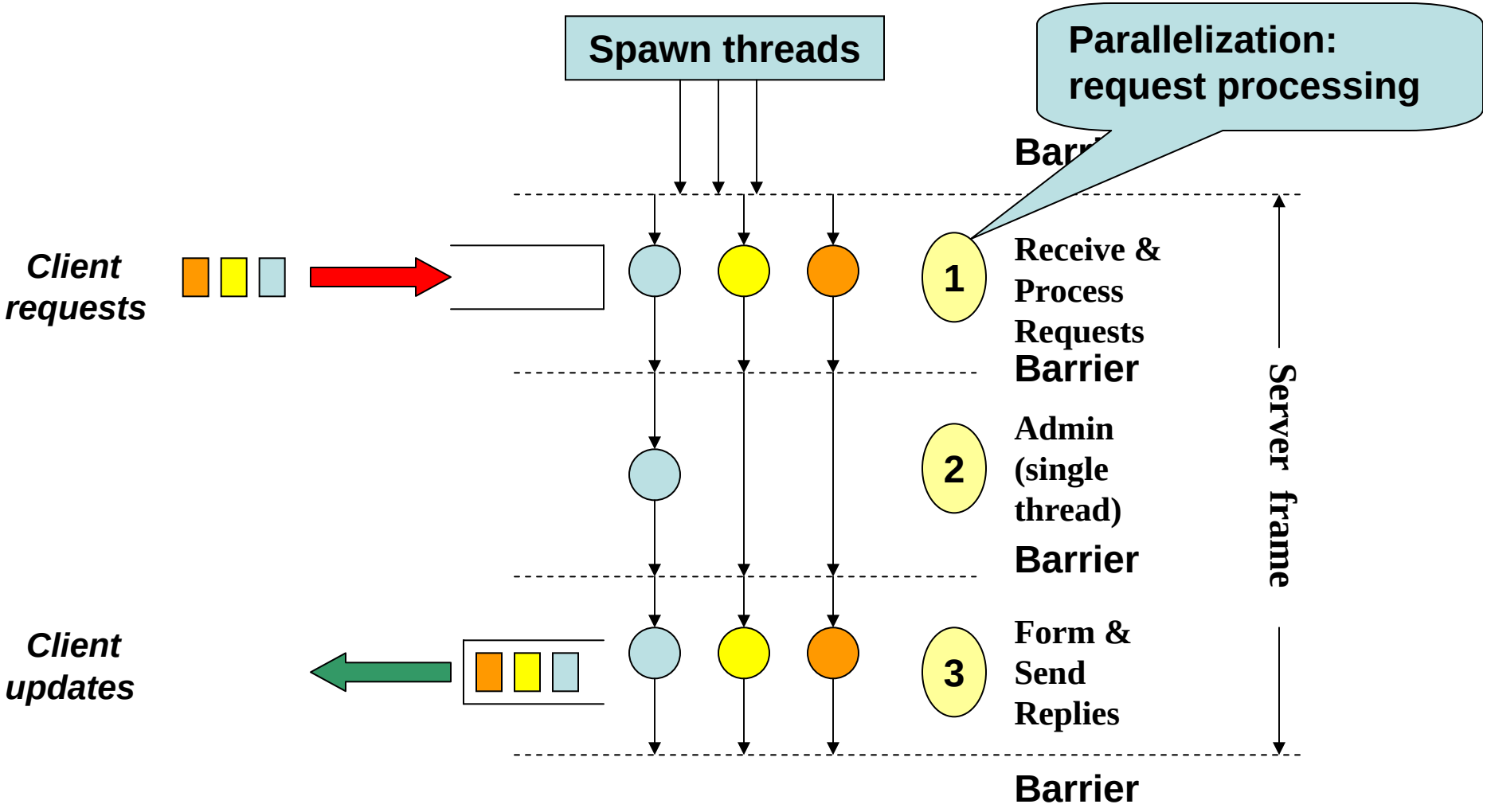


Game map



Areanode tree

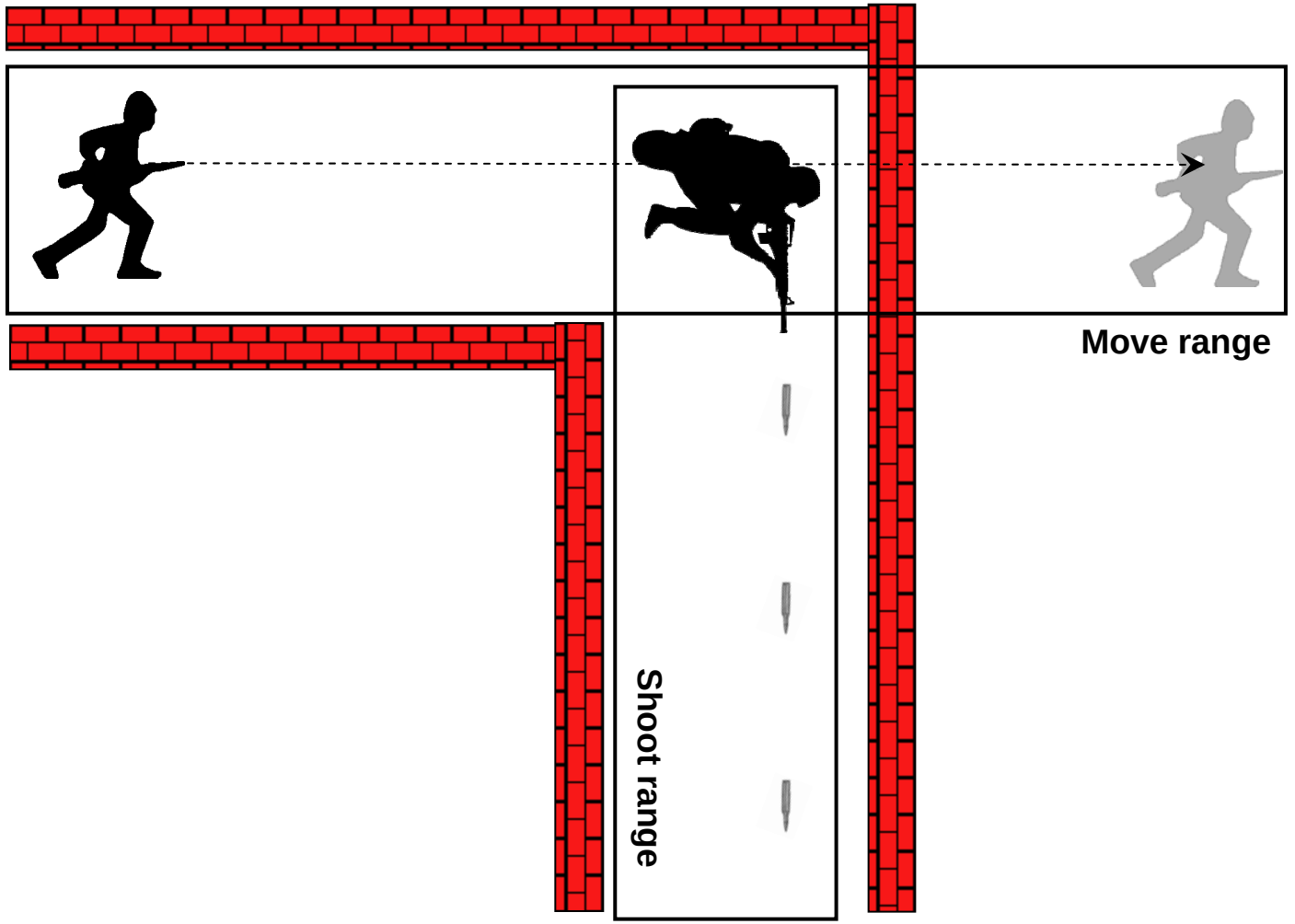
Server frame



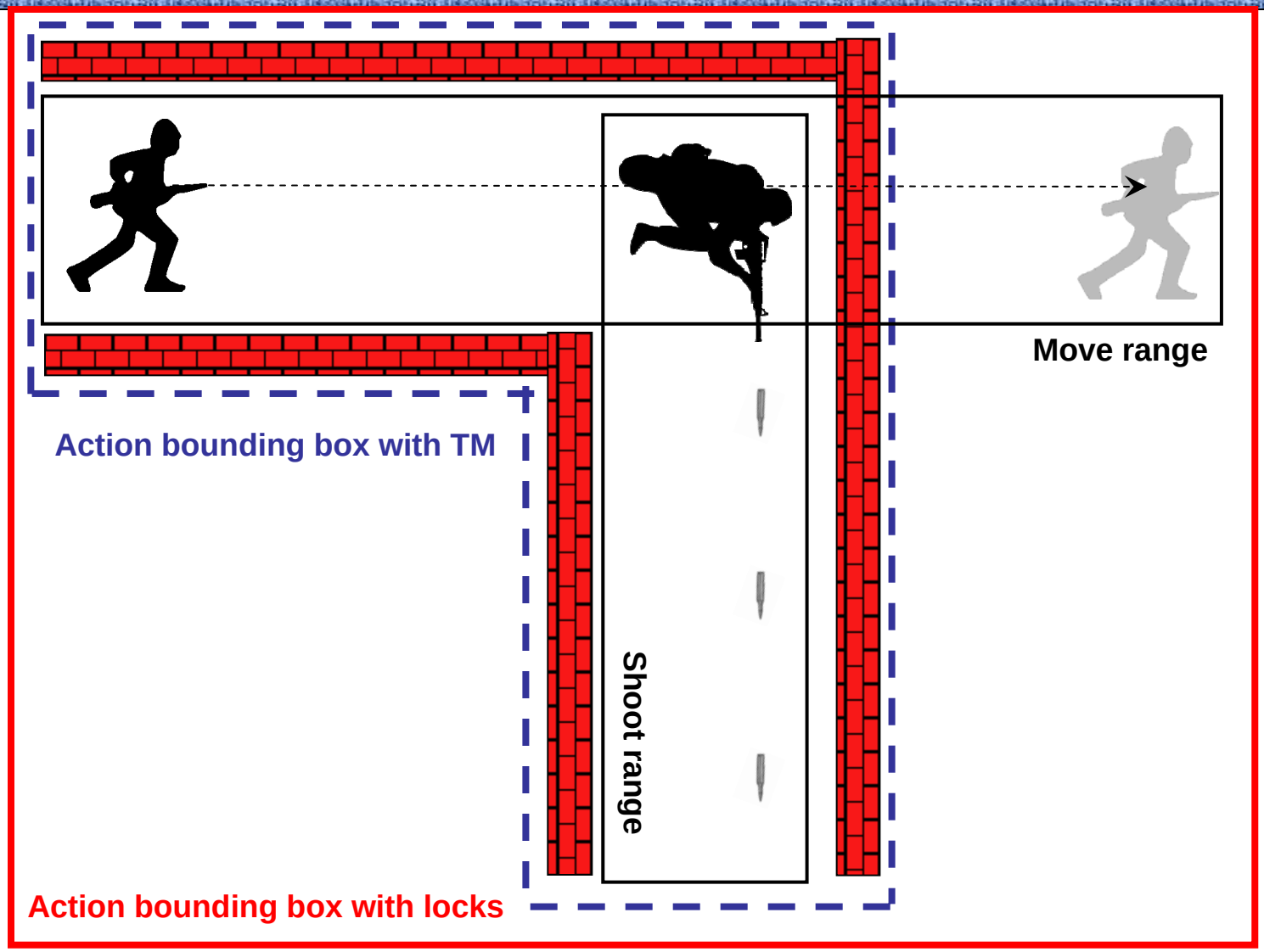
Outline

- Application environment: SynQuake game
- Parallelization issues
  - **False sharing**
  - Load balancing
- Experimental results

Action bounding box



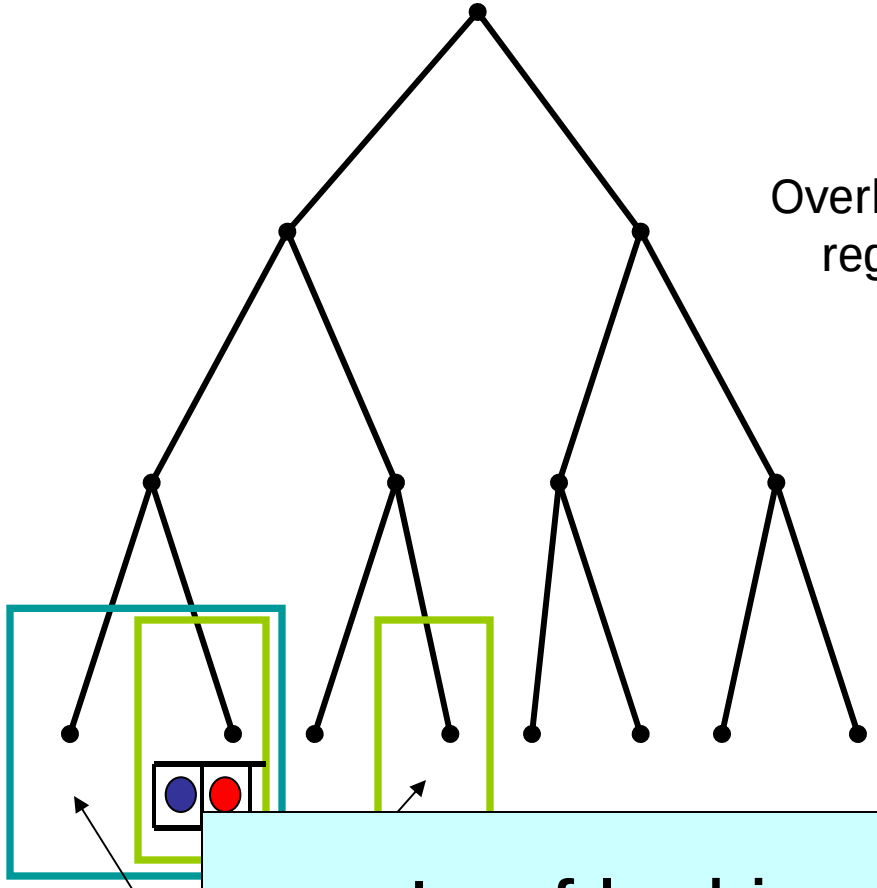
False sharing



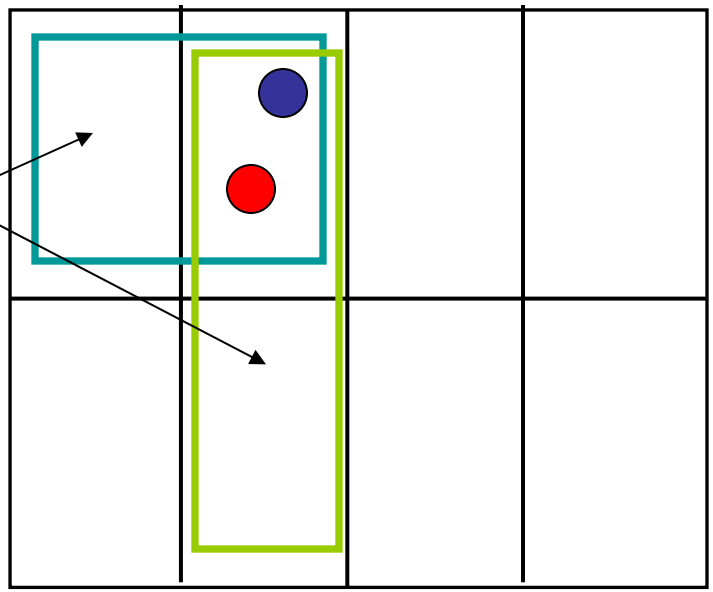
Synchronization algorithm: Locks

Areanode tree

Top-view of world



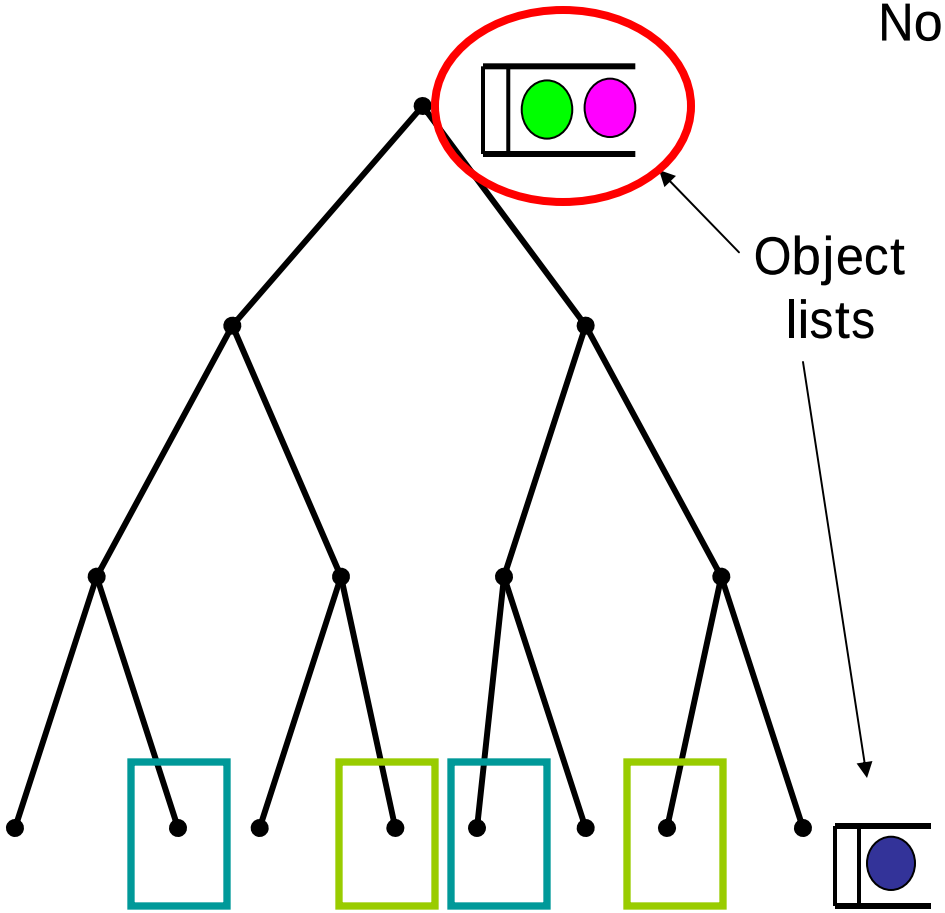
Overlapping regions

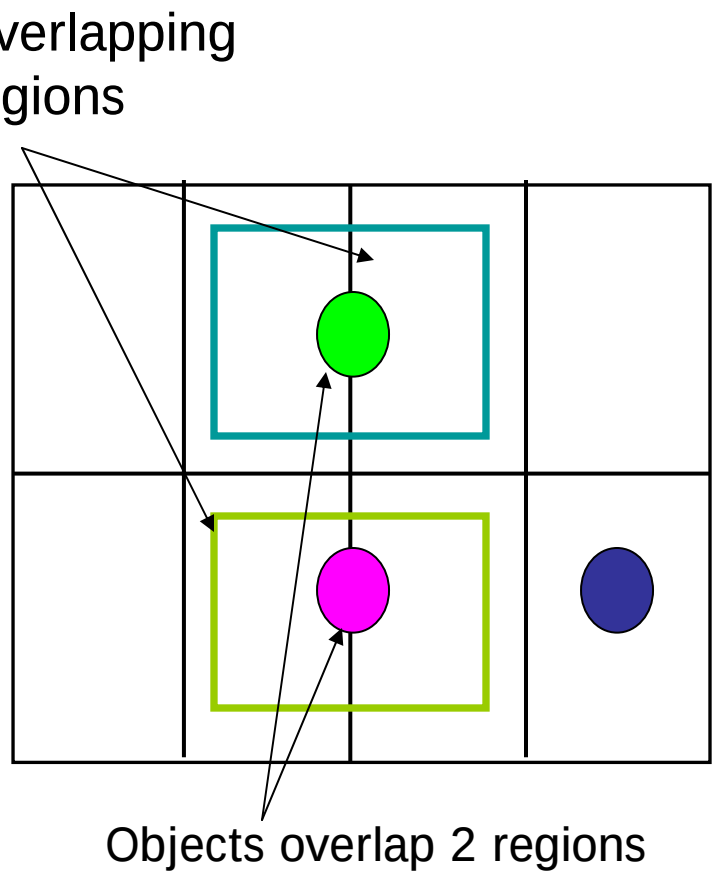


Lock c

Leaf locking: **True Sharing**

Synchronization algorithm: Locks





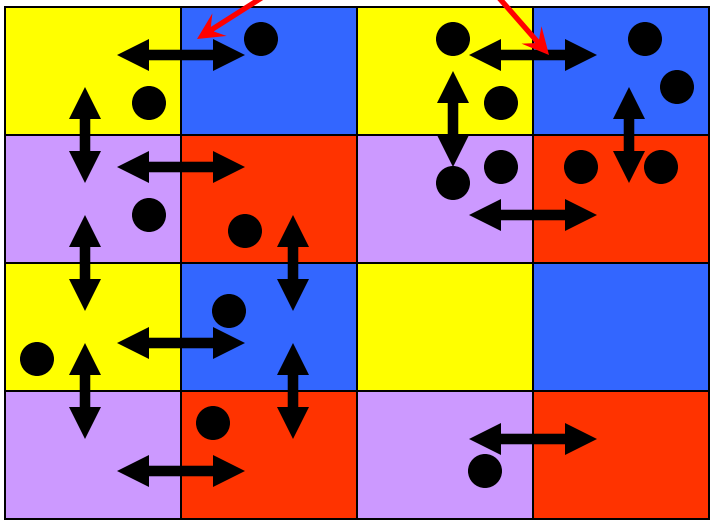
Parent node locking: **False Sharing**

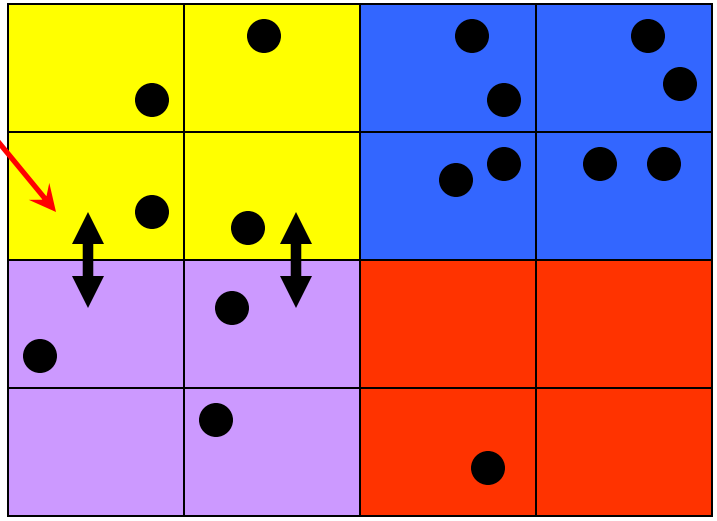
Outline

- Application environment: SynQuake game
- Parallelization issues
  - False sharing
  - **Load balancing**
- Experimental results

Load balancing tradeoff

Cross-border conflicts (true sharing) => synchronization





Good load distribution

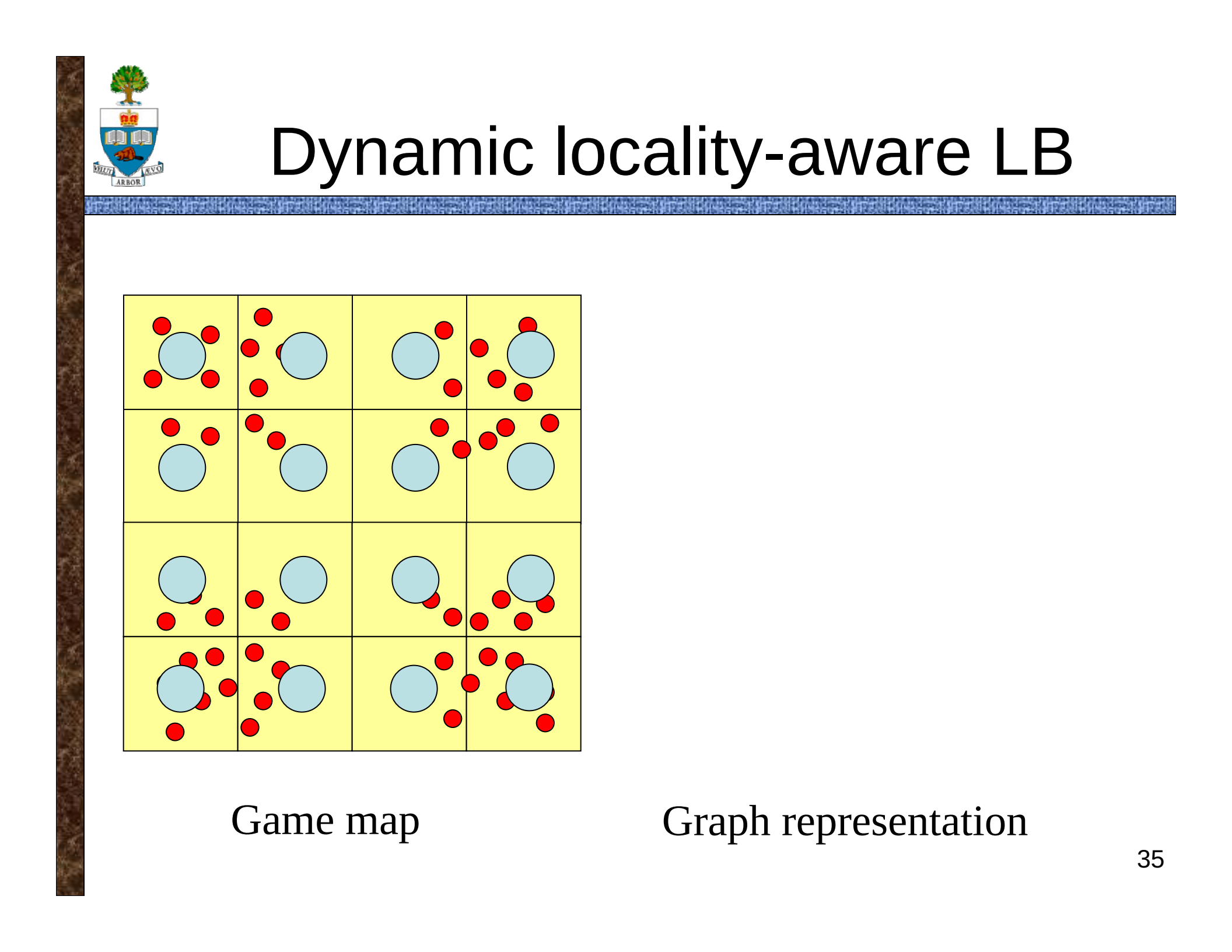
High synchronization

Bad load distribution

Low synchronization

Locality-aware load balancing

- Dynamically detect player hotspots and adjust workload assignments
- Compromise between load balancing and reducing synchronization

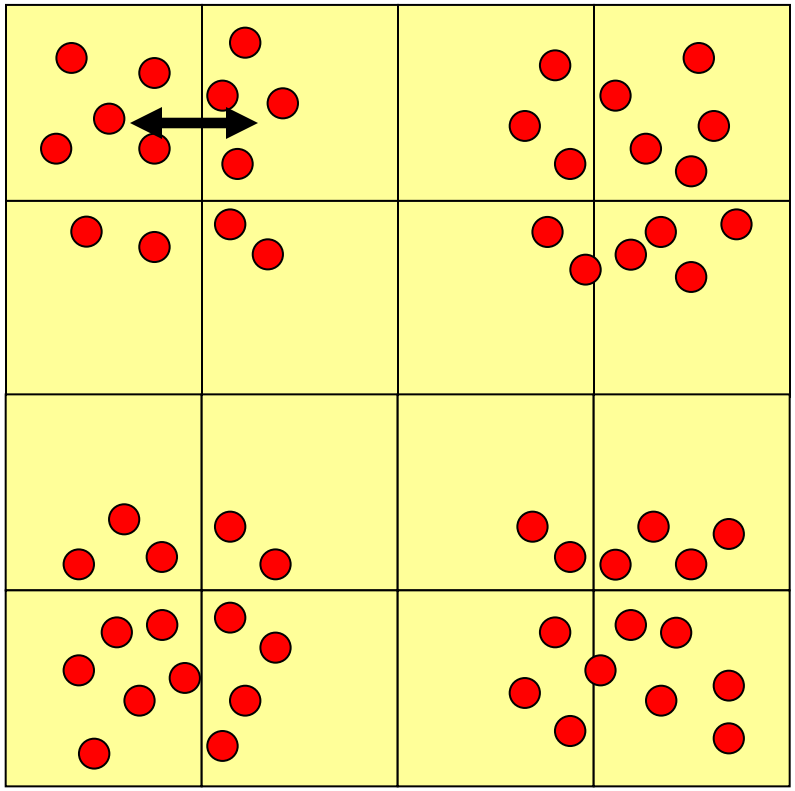


Dynamic locality-aware LB

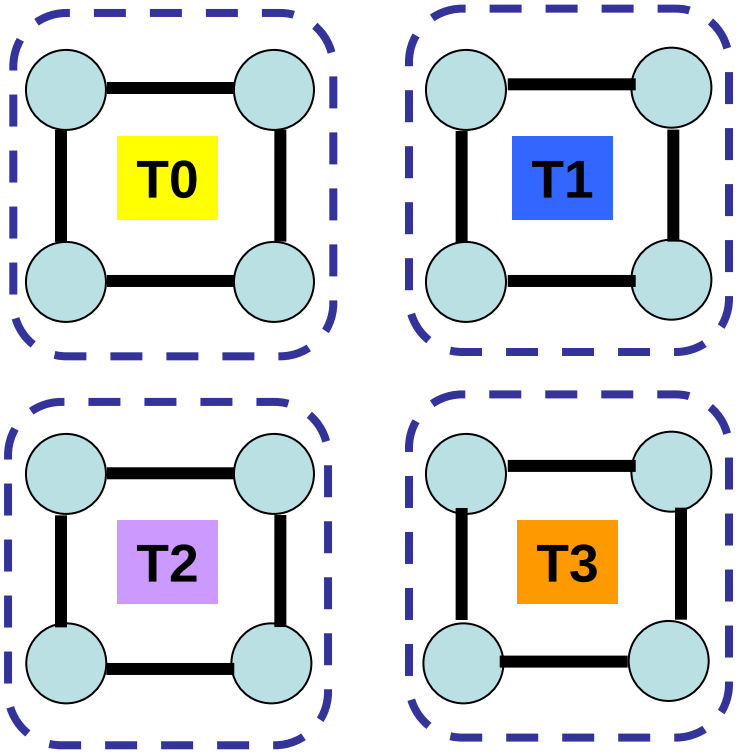
Game map

Graph representation

Dynamic locality-aware LB



Game map

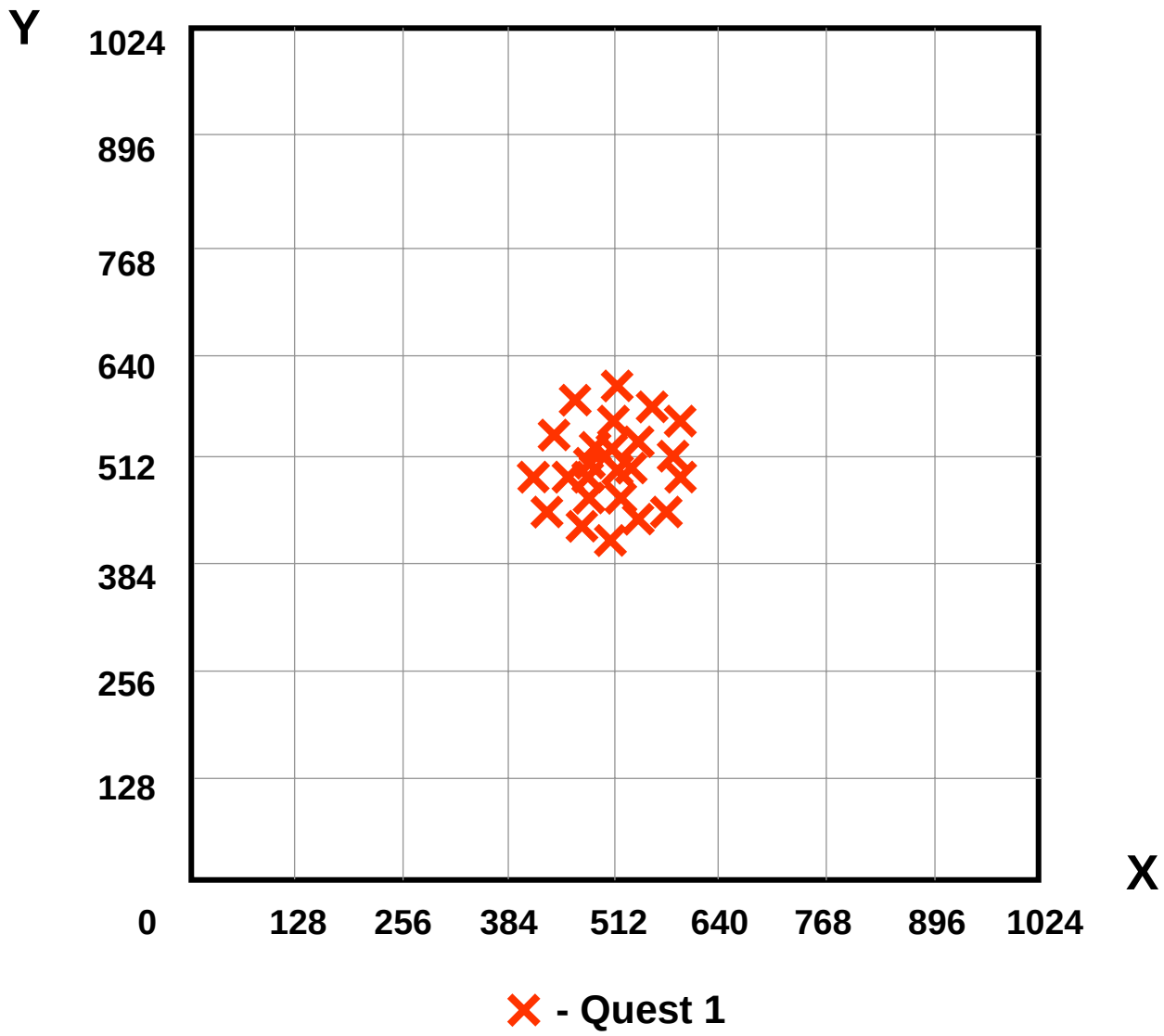


Graph representation

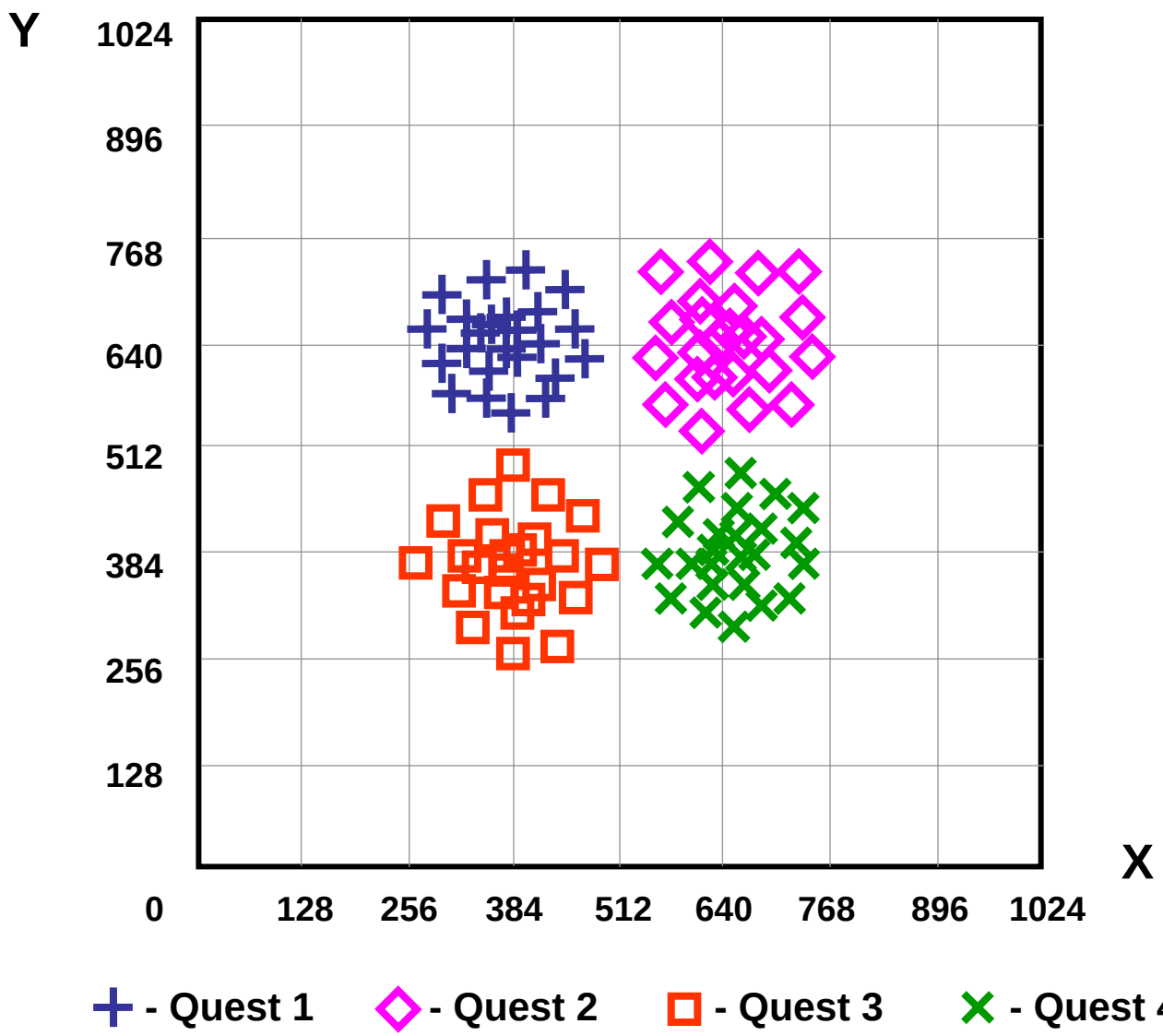
Experimental results

- Test scenarios: 1 – 8 quests, short/long range actions
- Performance comparison
  - Locks vs. STM scaling and performance
  - Influence of load balancing on scaling
- In the paper:
  - Varying the access tracking granularity for STM

Quest scenario: high contention

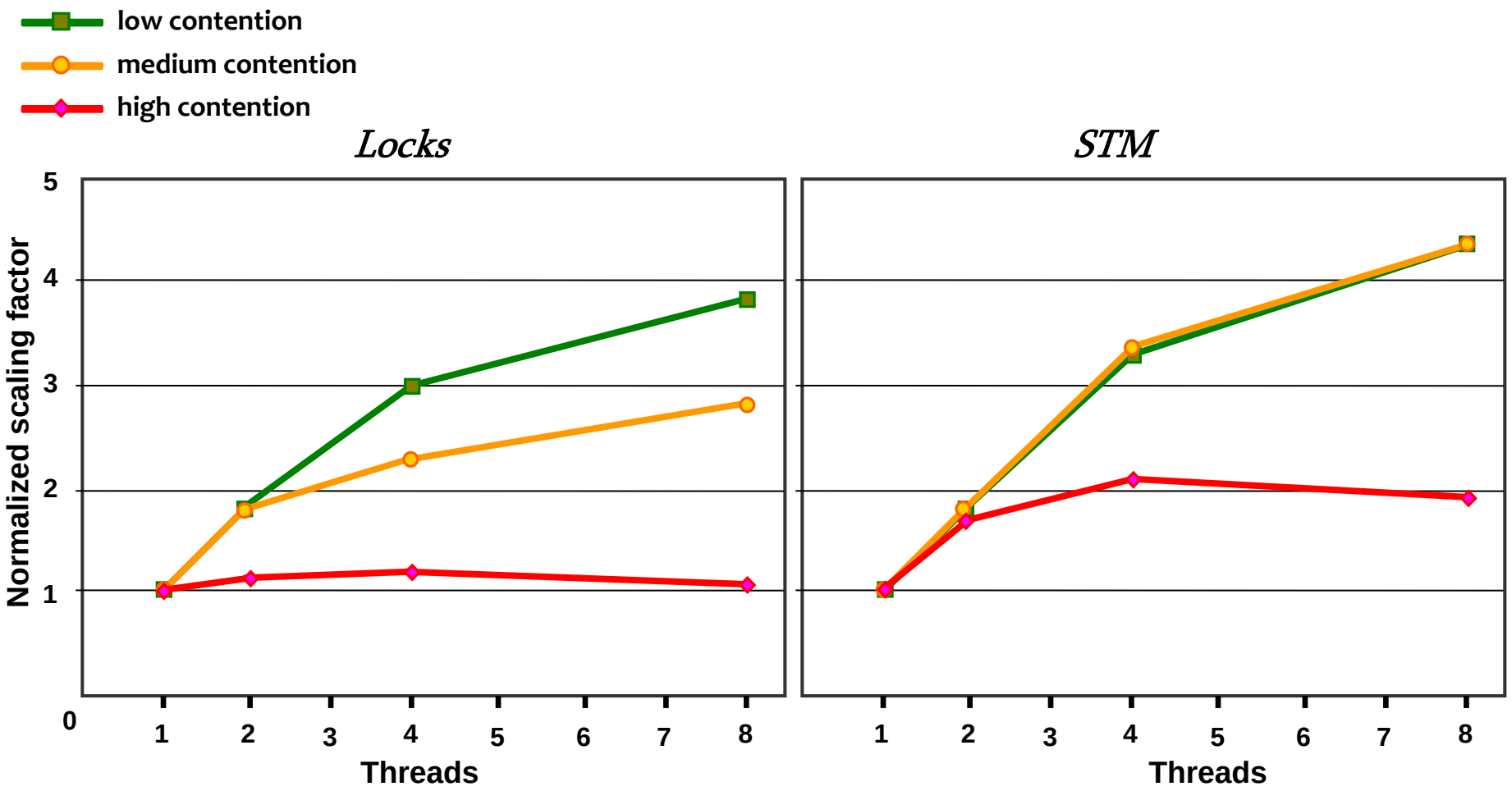


Quest scenario: medium contention



Scalability

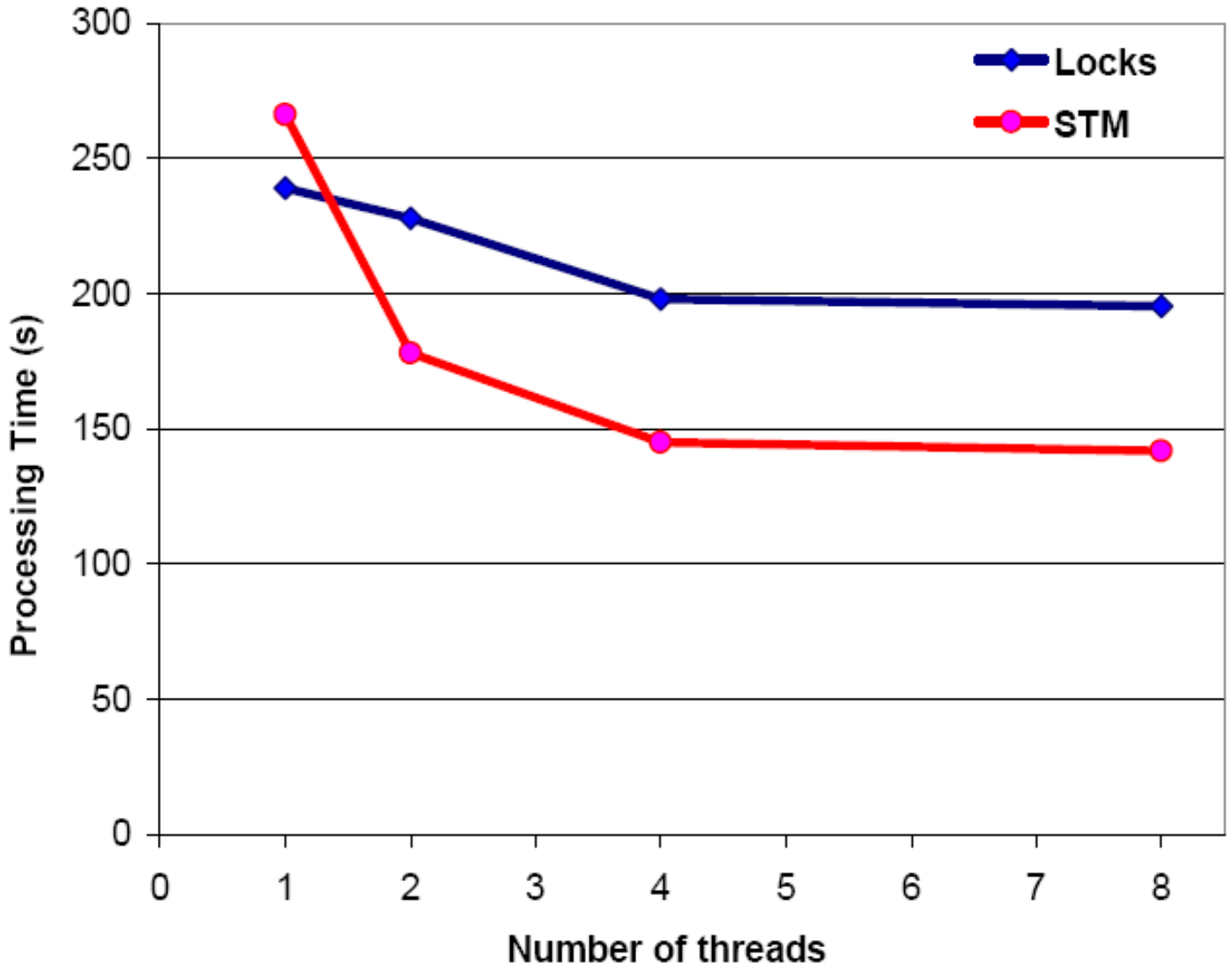
8 core machine



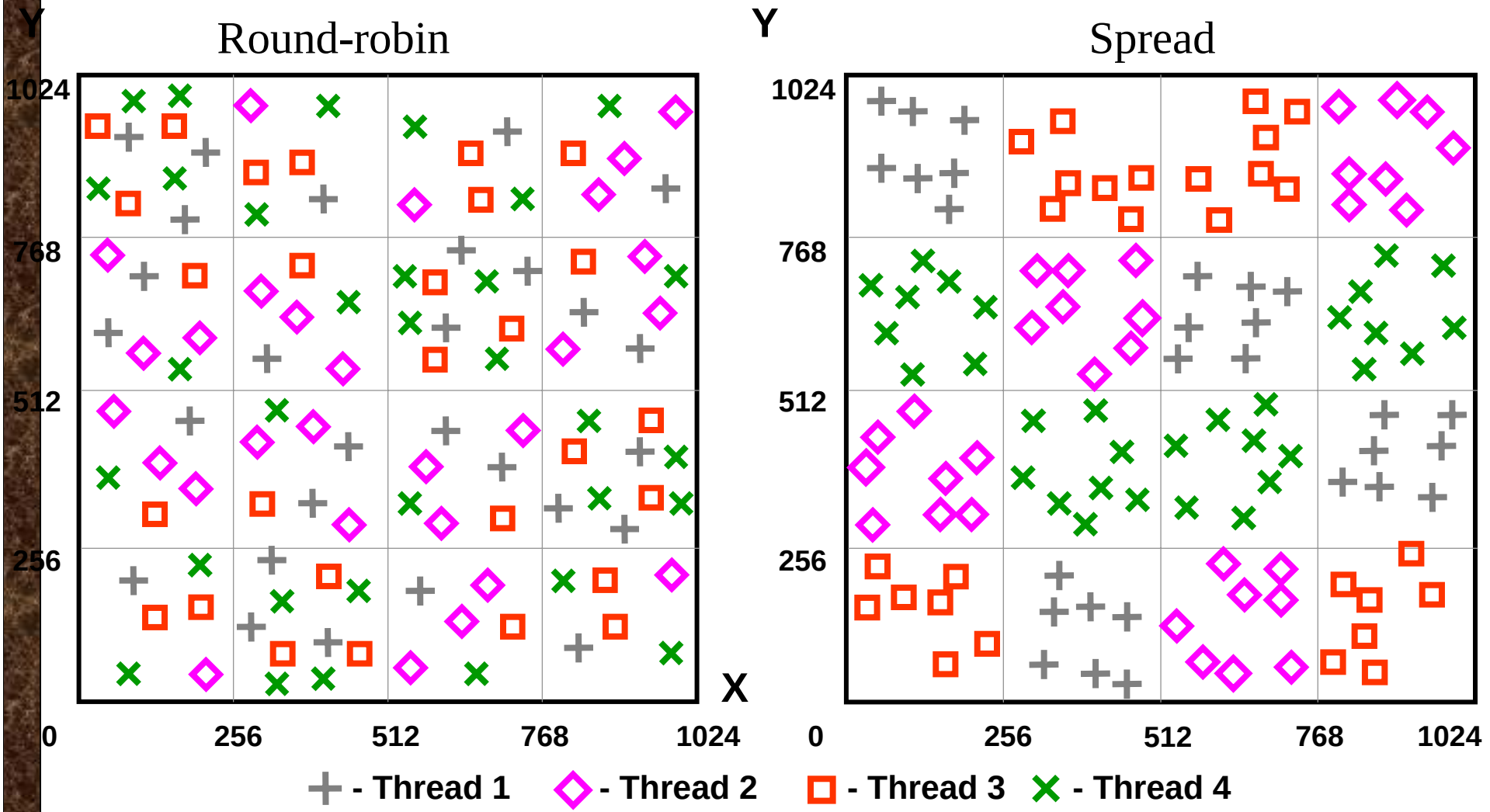
STM scales better in all 3 contention scenarios

Processing times

Medium contention

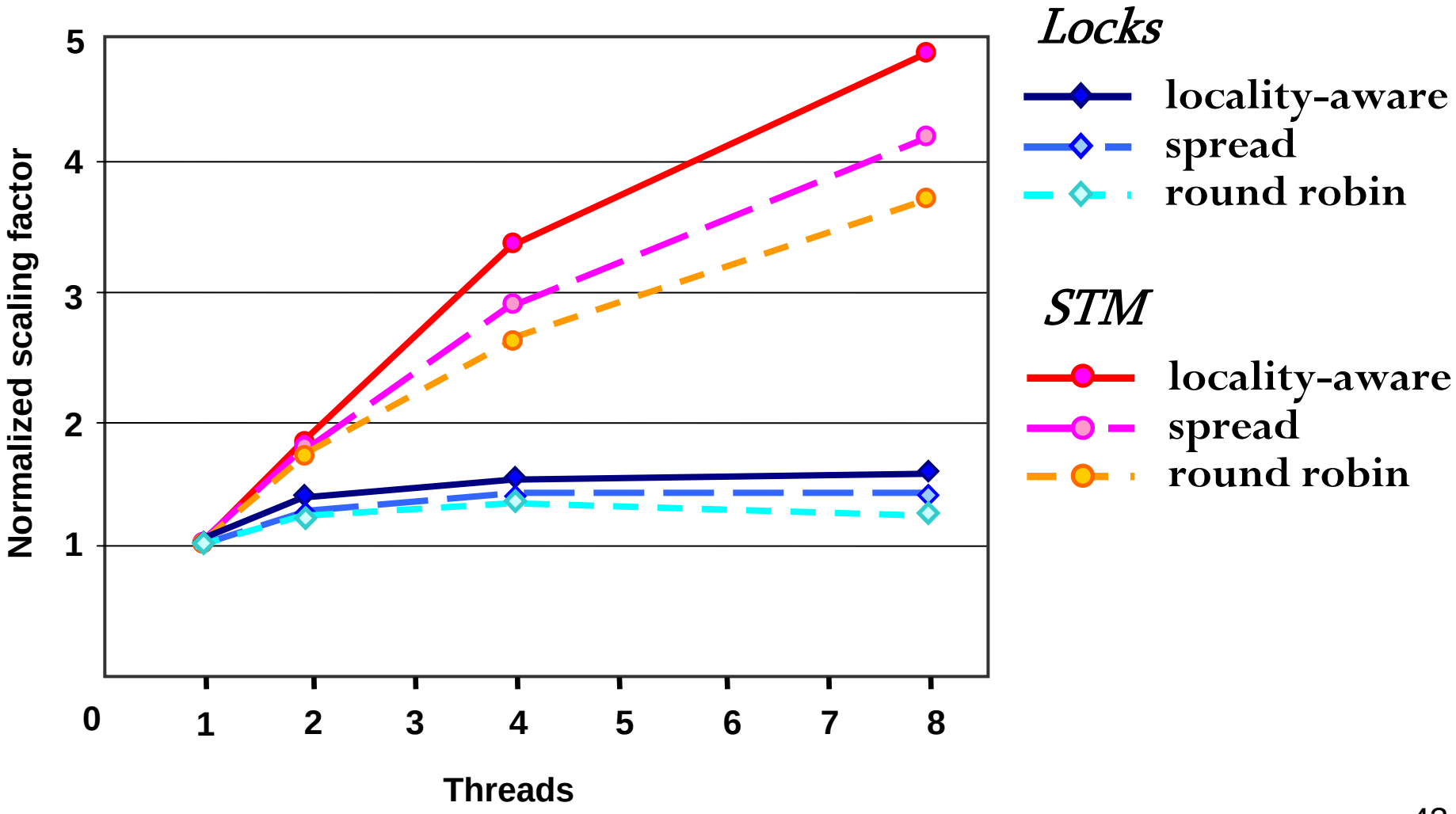


Baseline load balancing policies



Load balancing

Medium contention
Long range actions



Conclusions

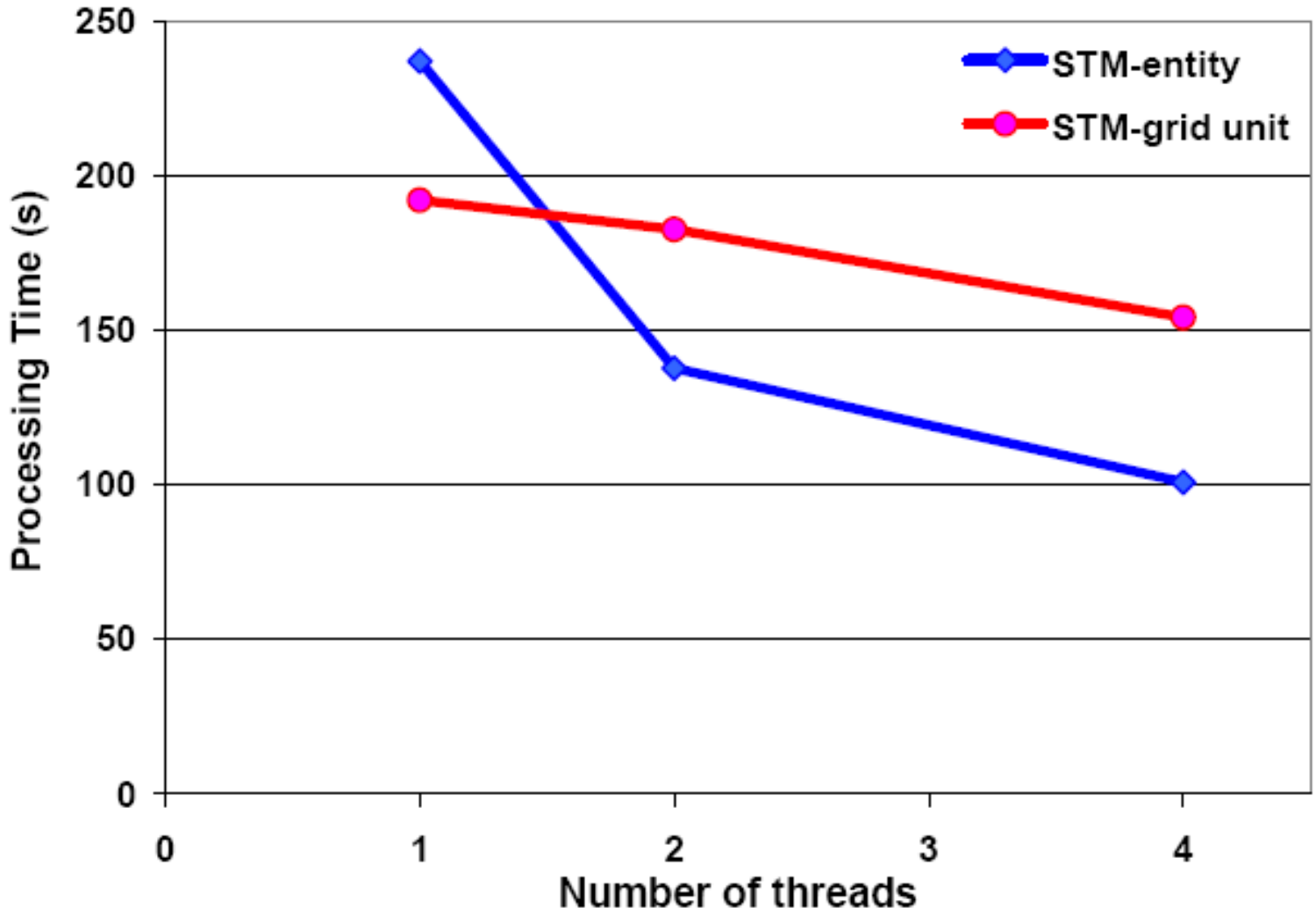
- First application where STM outperforms locks:
  - Overall performance of STM is better at 2,4,8 threads in all scenarios
- STM eliminates false sharing through on-the-fly collision detection
  - Unlocks the potential of using locality-aware load balancing to reduce true sharing

SynQuake vs. Quake

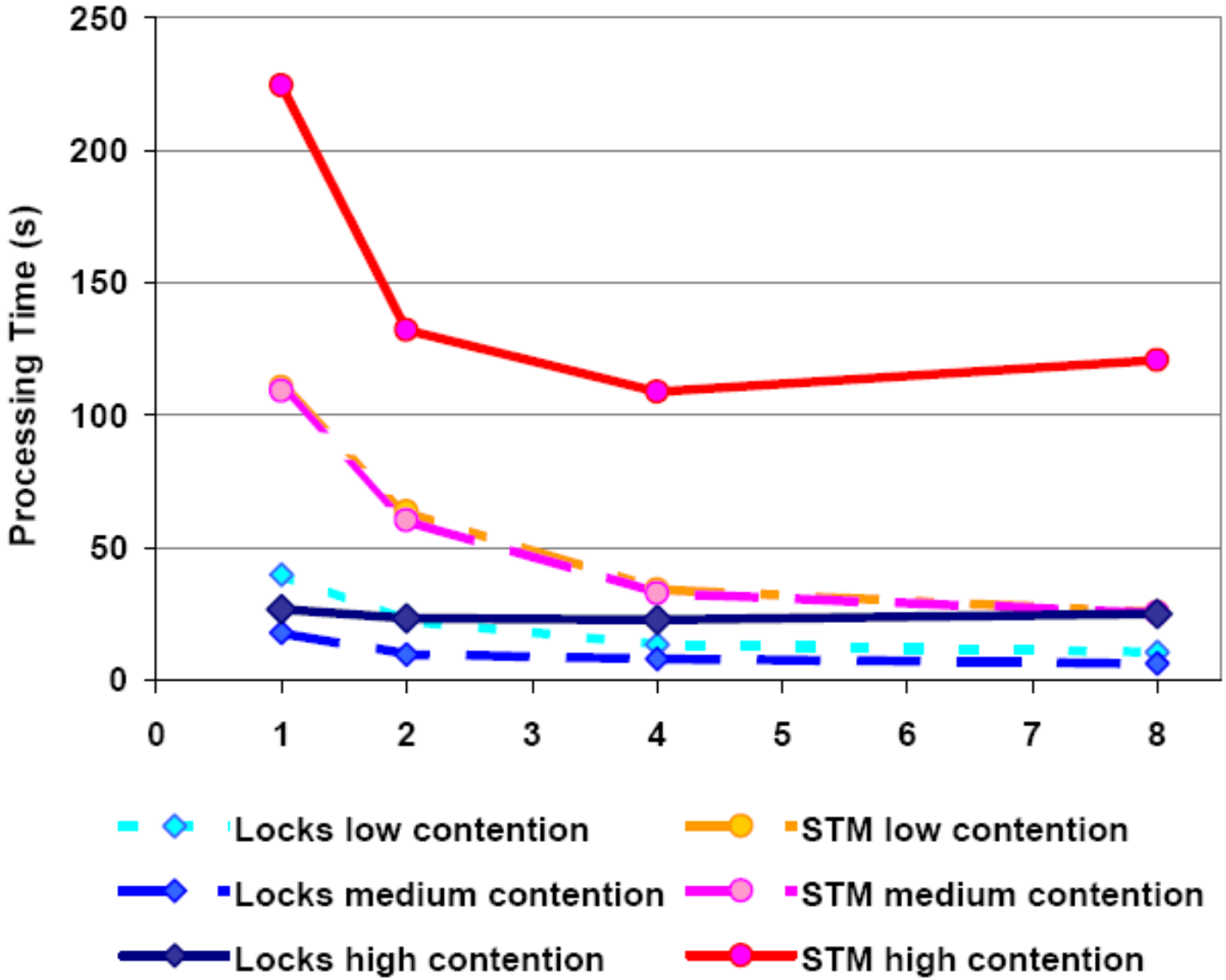
- SynQuake - thorough evaluation of tradeoffs
- Quake
  - More complex graphics
  - More world physics computation
- More physics computation ⟹ STM overhead becomes negligible
- Performance results expected to hold for complex 3D games

Thank you !

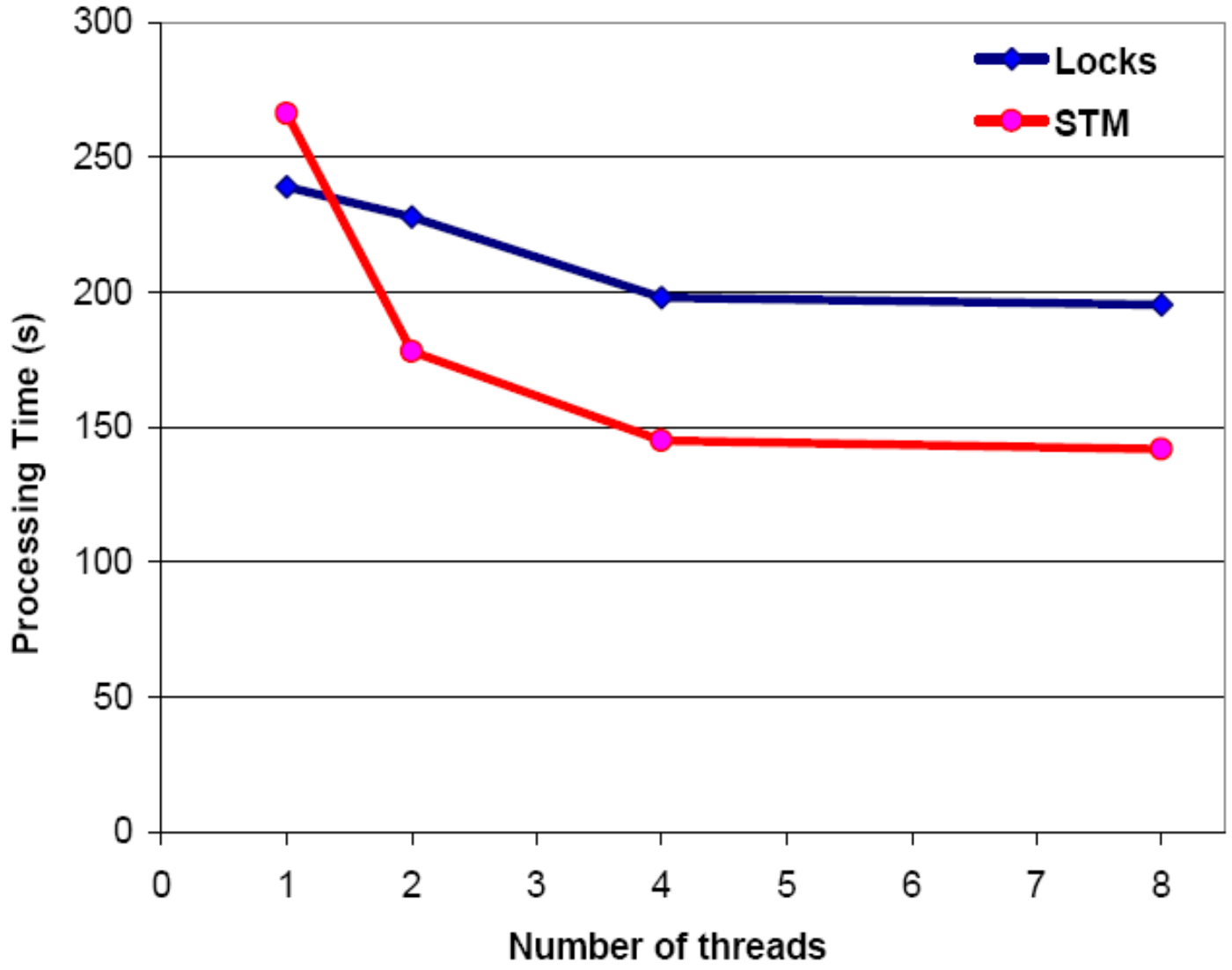
STM: access tracking granularity



STM - Overheads

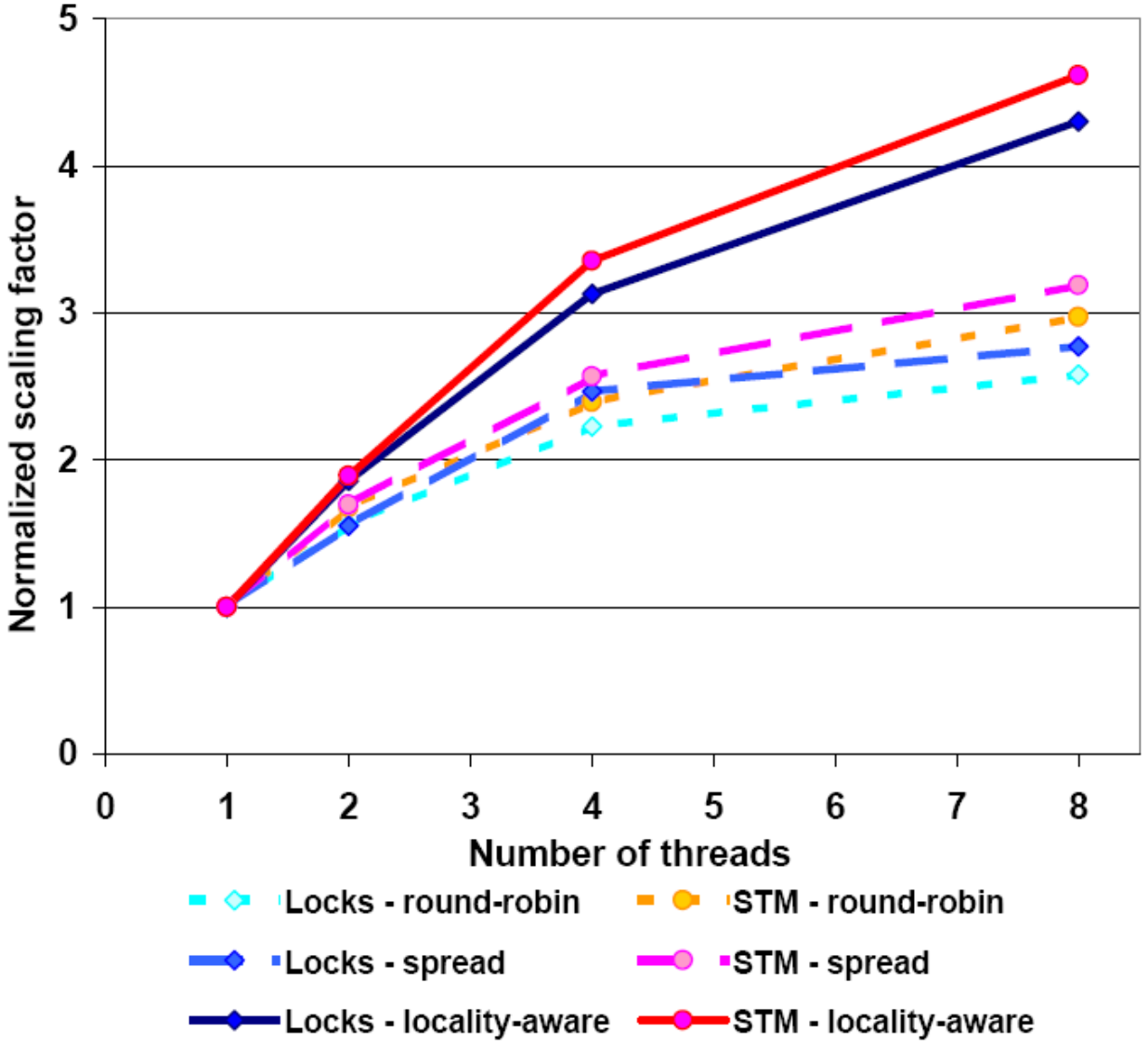


Processing times



Load balancing

- low false sharing -



LibTM

- LibTM: goal of providing high flexibility
  - Concurrency control
  - Access tracking granularity
- Widespread reliability problems among existing TM systems available at the time
  - e.g. Memory management limitations
  - Dragojevic ’08 – “Dividing transactional memories by zero” – DSTM2, RSTM, TL2, TinySTM

LibTM statistics

- Locality-aware load balancing
- Over 2 million transactions

Contention Level	No. threads	Abort rate	Write ratio
Low	1	0%	22.74%
	2	1%	22.70%
	4	2%	22.65%
	8	6%	22.56%
Medium	1	0%	4.65%
	2	1%	4.80%
	4	2%	4.76%
	8	3%	4.77%
High	1	0%	0.62%
	2	1%	0.62%
	4	2%	0.63%
	8	2%	0.63%