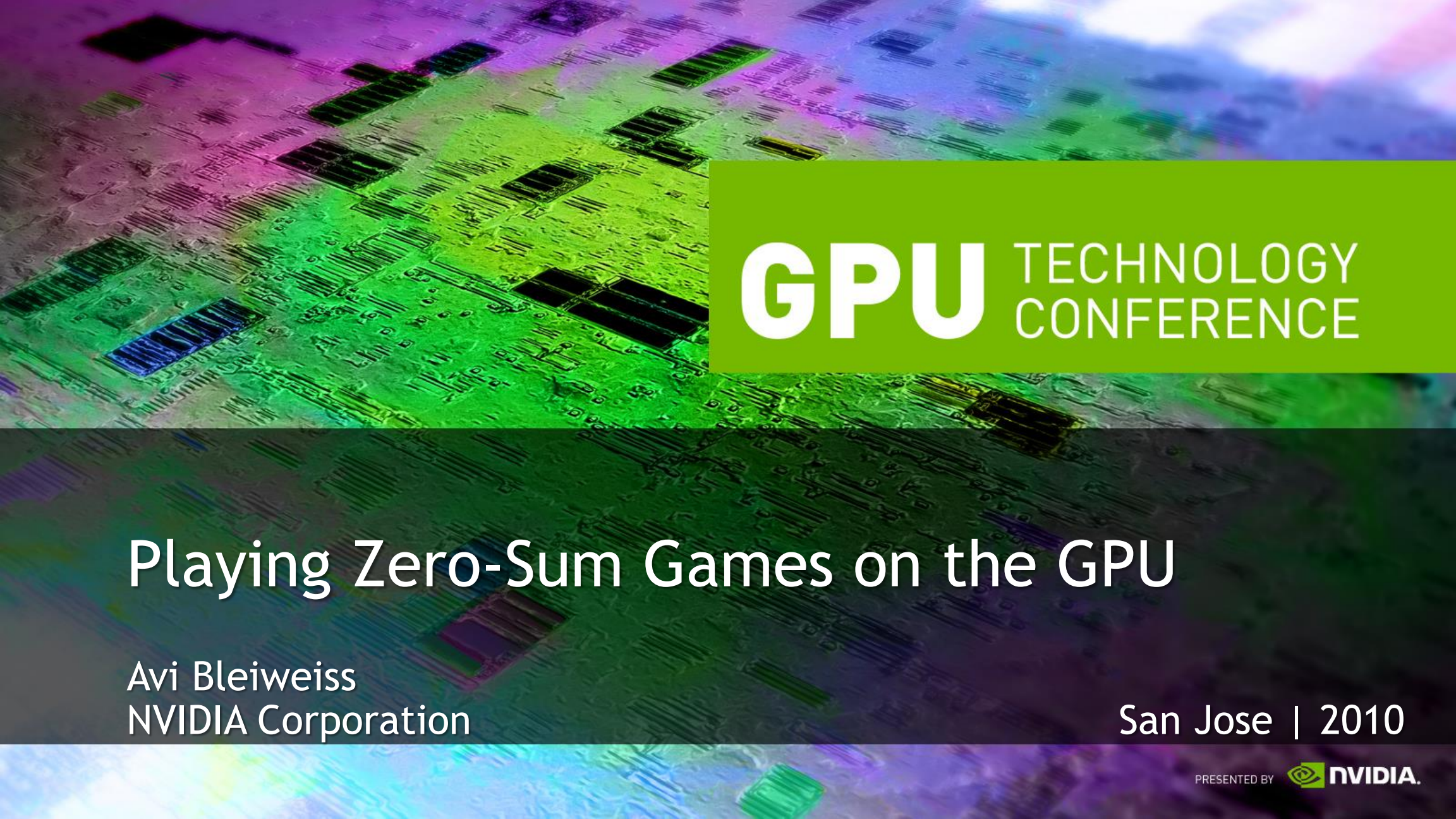


Playing Zero-Sum Games on the GPU

Avi Bleiweiss
NVIDIA Corporation

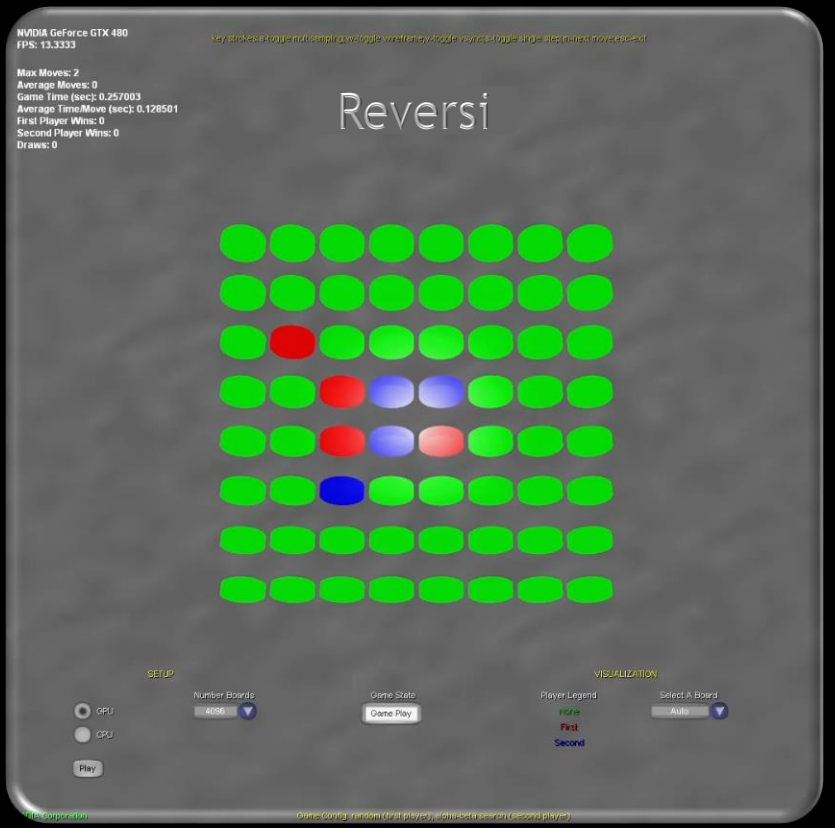
San Jose | 2010

PRESENTED BY NVIDIA.

Zero-Sum

- One’s gain, other’s loss
- Perfect info
- Multi player game
  - Simple and involved

Matching Pennies	Head	Tail
Head	1,-1	-1,1
Tail	-1,1	1,-1

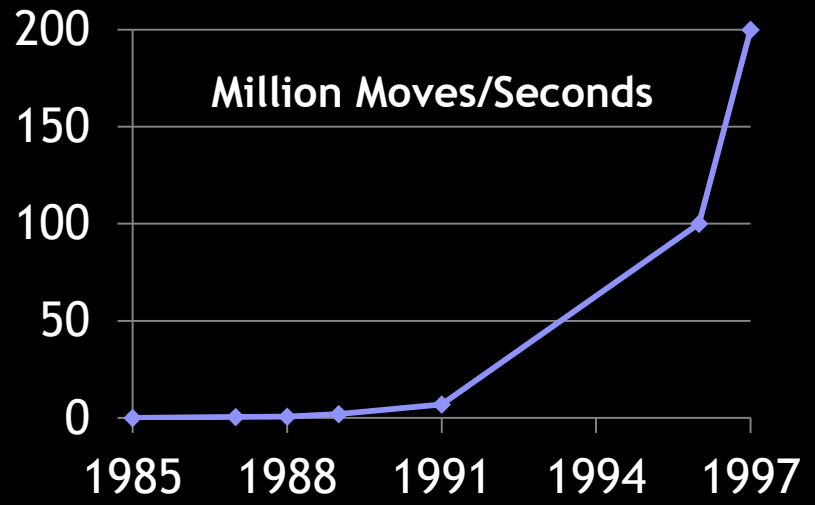


Deep Blue

32 CPUs

512 Chess ASICs

1.15B transistors



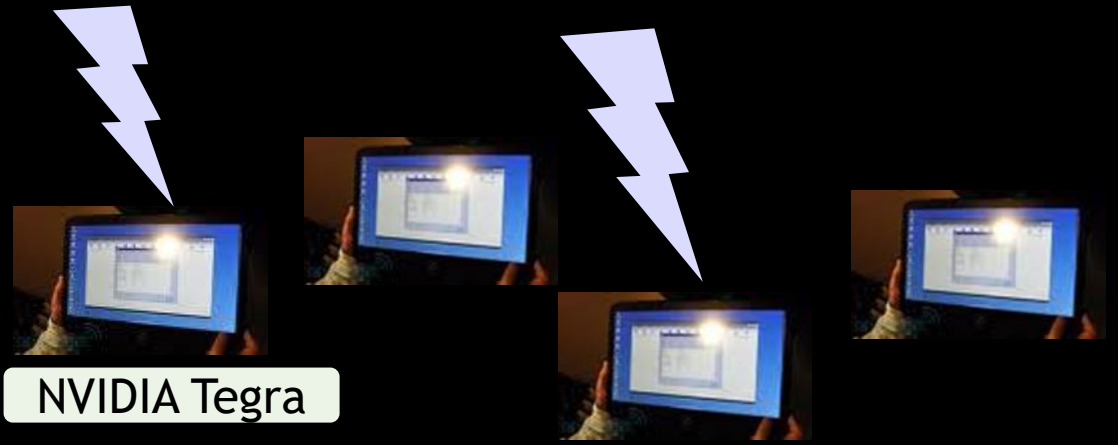
6’5” tower pair

1.4 tons

100M$

Motivation

- Play as you go
  - Thousands players
- Game cloud
  - GPU computing
- Mobile computer
  - 3D graphics



Problem

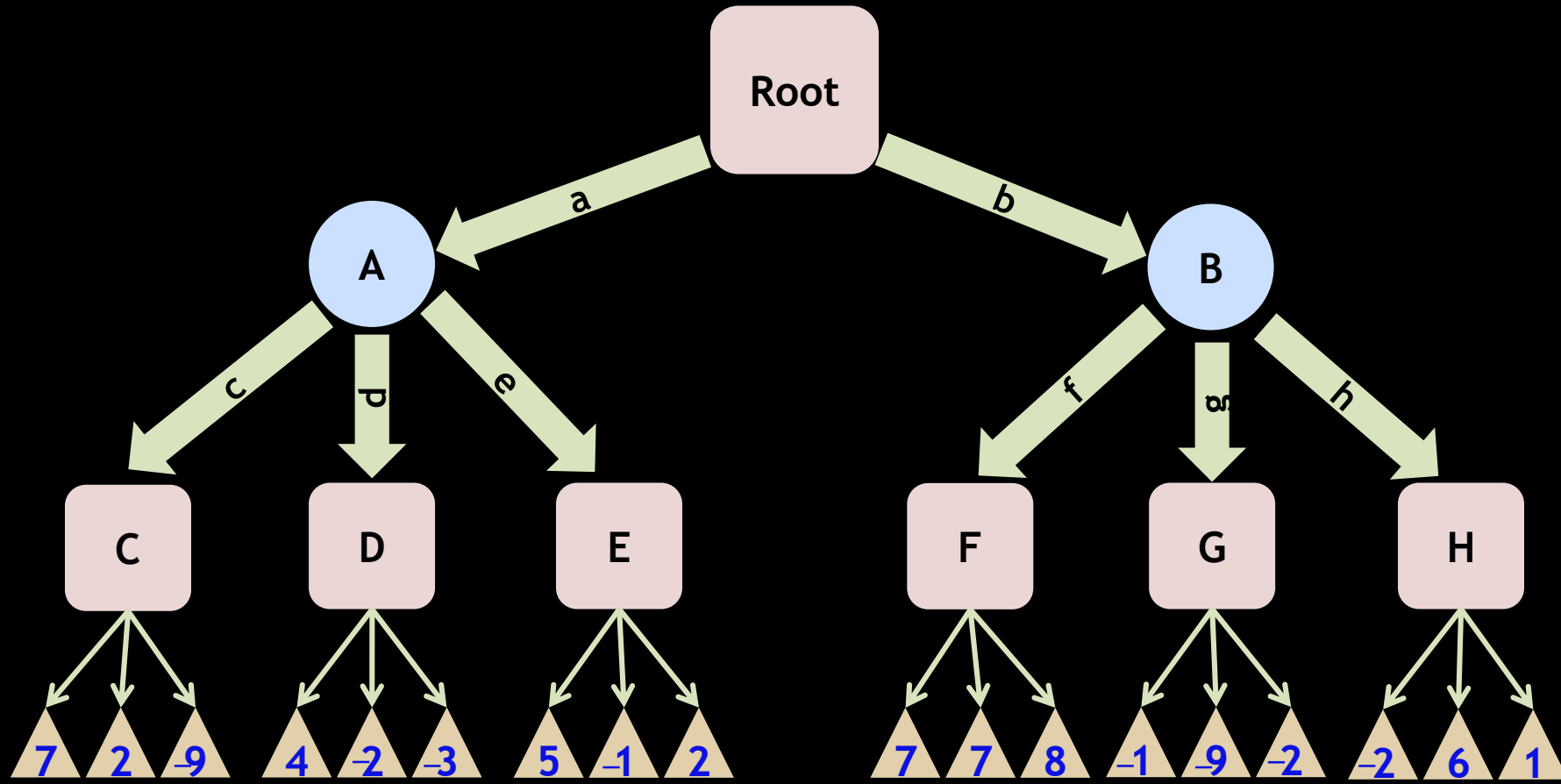
Game

- Two player
- Maximize look ahead
- Complexity
  - 10^{25} for 4x4x4 Tic-Tac-Toe
  - 10^{120} for Chess

Search

- Efficient parallel
  - Single game
  - Simultaneous matches
- Graceful stack
- Linear scale

Game Tree

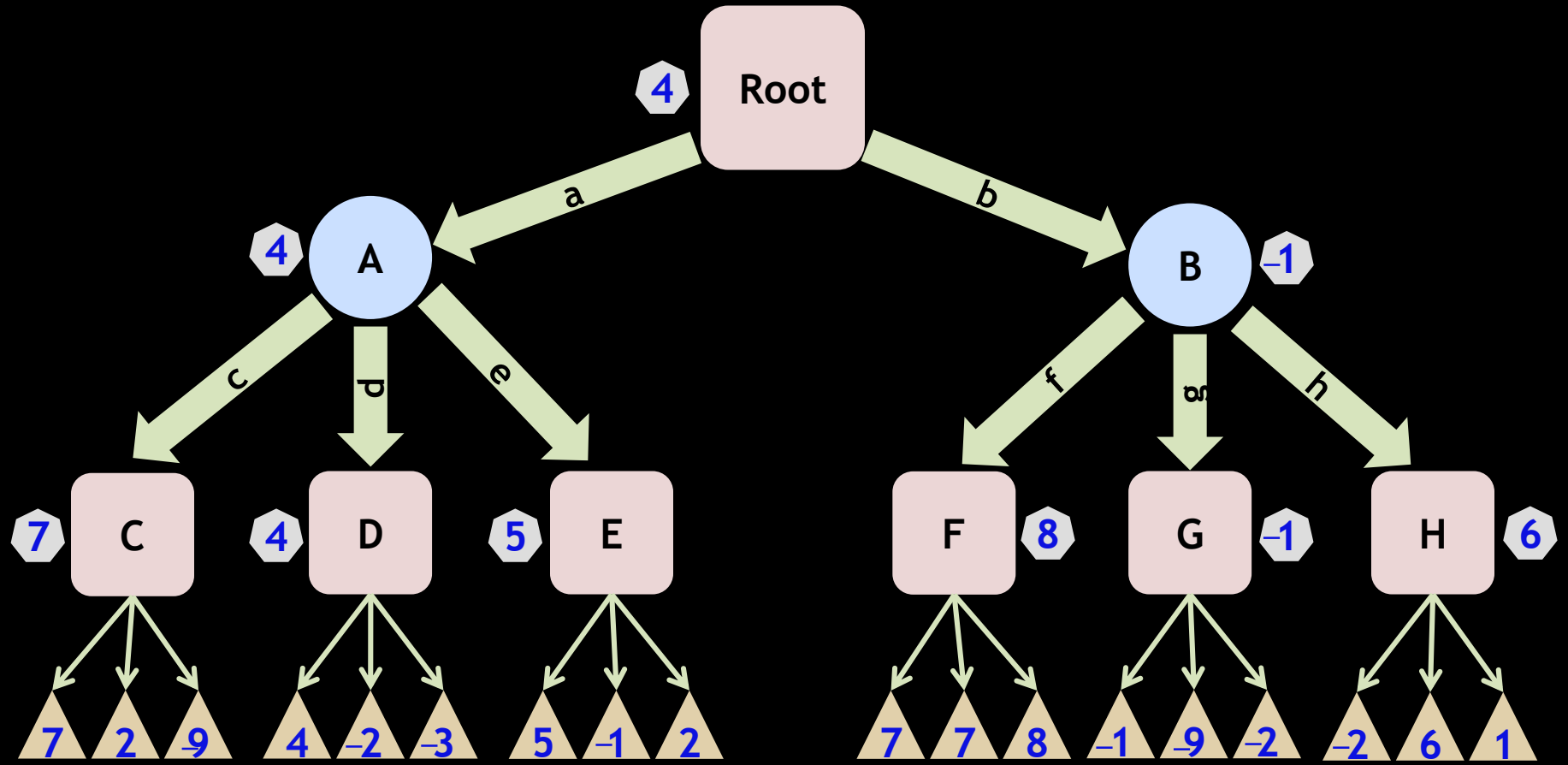


Mini-Max

- Build and search
- Unbound DFS
  - All nodes visited
- Non tail recursive
- Depth limited

```
MiniMax(node,max)
  if(isLeaf(node))
     return evaluate(node)

  if(max) then rank ← −∞
  else rank ← ∞

  foreach(s_i in successors(node))do
    tmp ← MiniMax(s_i,!max)
    if(max)then
      rank ← MAX(rank,tmp)
    else
      rank ← MIN(rank,tmp)
  return rank
```

Principal Variation

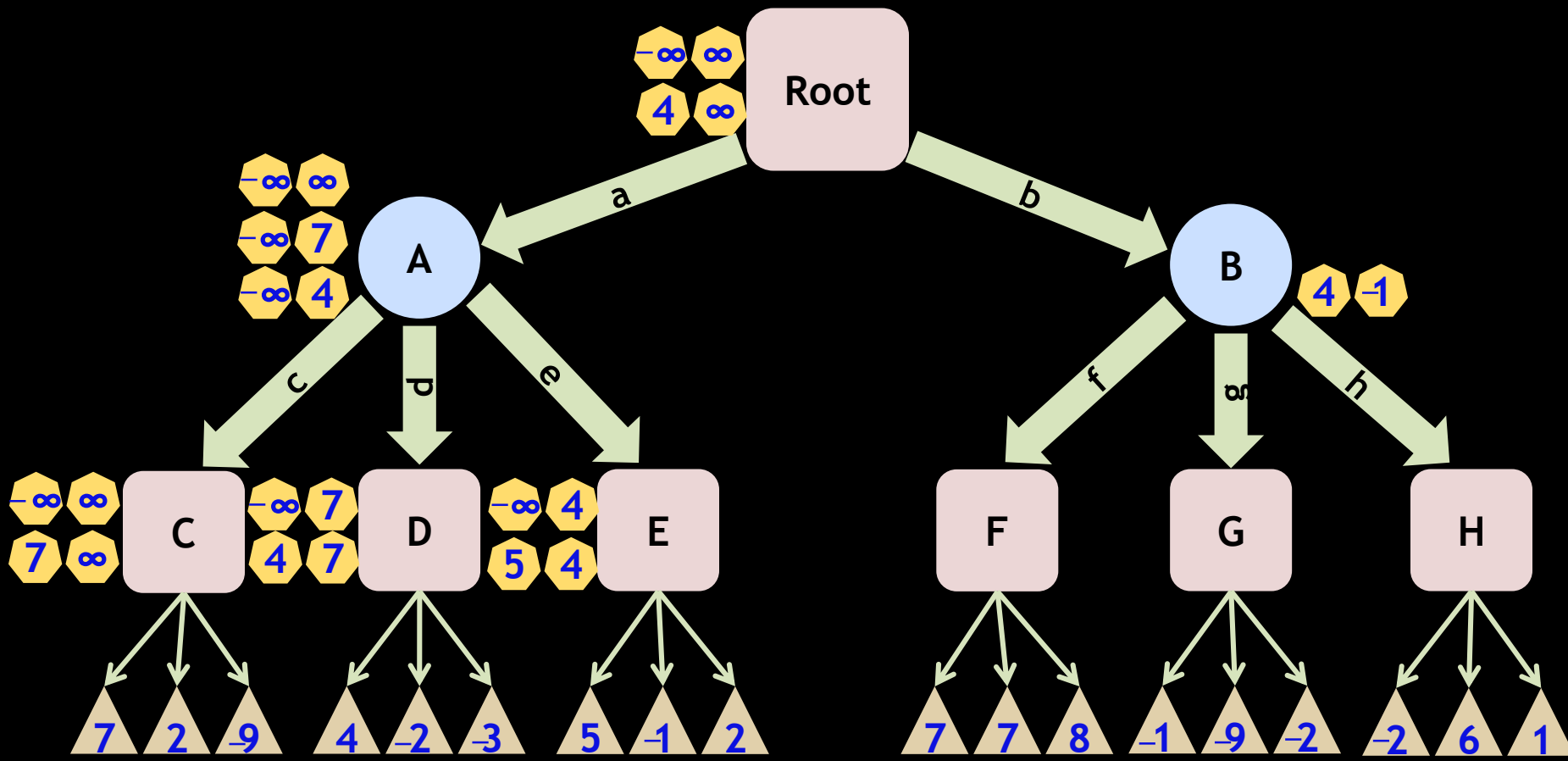


Alpha-Beta

- Enhances Mini-Max
- Elegant, efficient
  - Prunes nodes
- Perfect game
  - Possible in cases

```
AlphaBeta(node,max,α,β)
  // termination, initialization

  if (α > β) return rank

  foreach(s_i in successors(node))do
     tmp ← AlphaBeta(s_i,!max,α,β)
     if (max) then
        rank ← MAX(rank,tmp)
        α ← MAX(α,rank)
     else
        rank ← MIN(rank,tmp)
        β ← MIN(β,rank)
  return rank
```

Pruning



Optimization

Aspiration Search

- Tree value known
- Narrow window
- Re-search if fails

[Marsland, T. A. 1986]

Principal Variation Search

- Non PV nodes
  - beta = alpha + 1
- Full window PV nodes
- Perfect ordered tree

Iterative Deepening

- Fixed depth searches
- Transposition table
- Hash branch positions

Parallelism

Principal Variation Split

- Strongly ordered tree
- Synchronization bound
- Load imbalance

Young Brothers Wait Concept

- Parallel at any node
- Processor owns node
- Scales to # processors

Dynamic Tree Splitting

- Processors share node
- Global job list
- Reasonable speedup

[Feldmann, R. 1993]

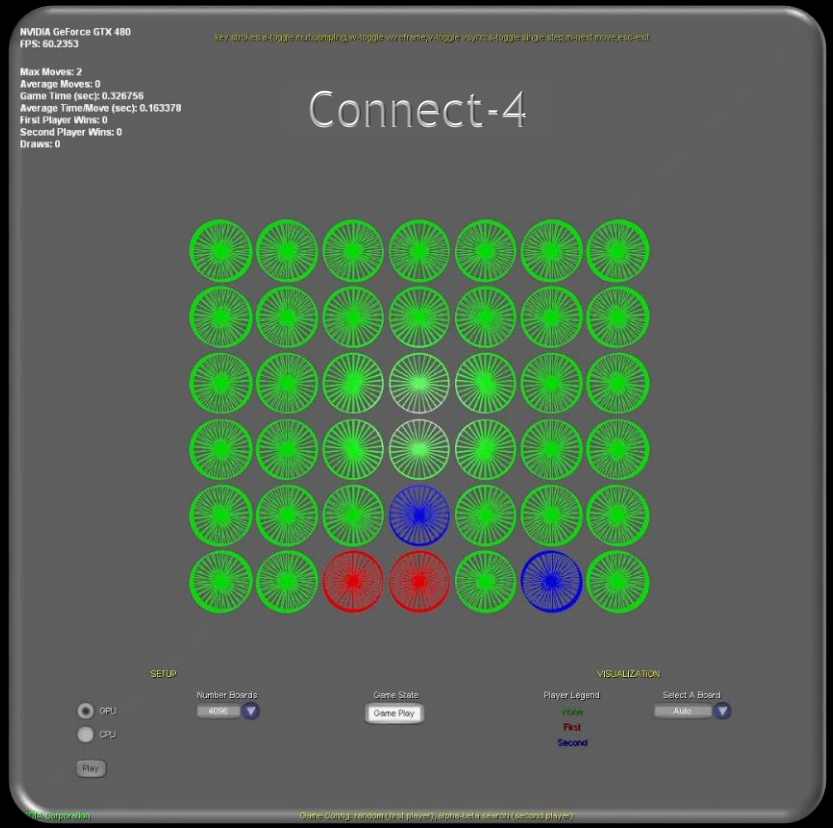
Challenges

- Deep recursion, limited stack
- Divergent, irregular threads
- Dynamic parallelism
- Low arithmetic intensity

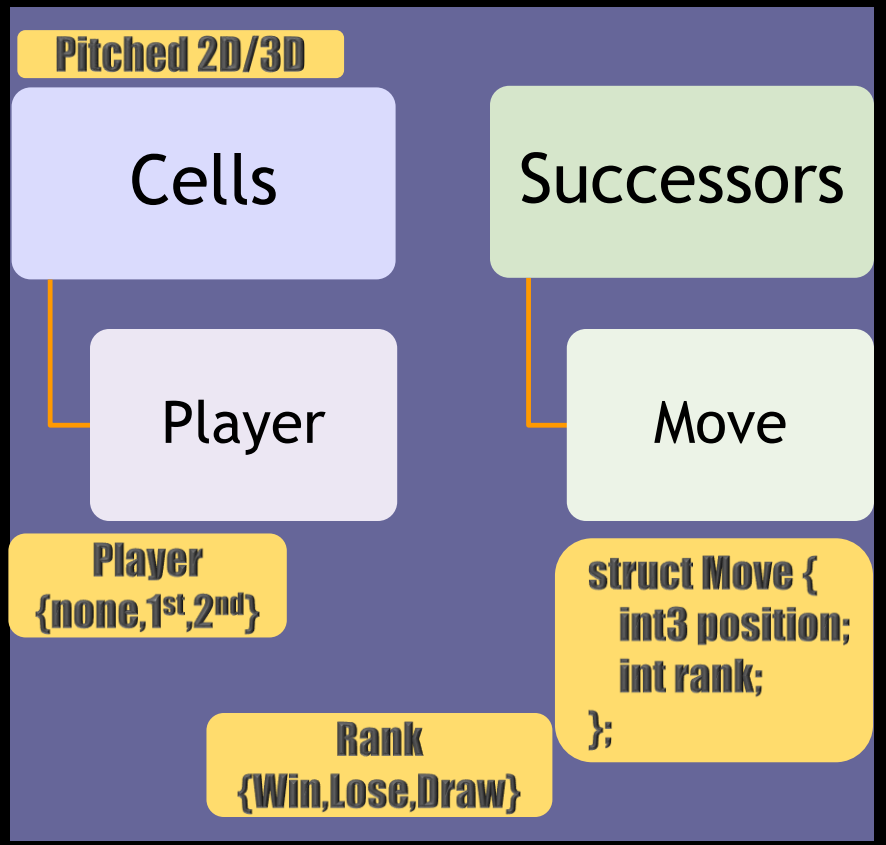
Implementation

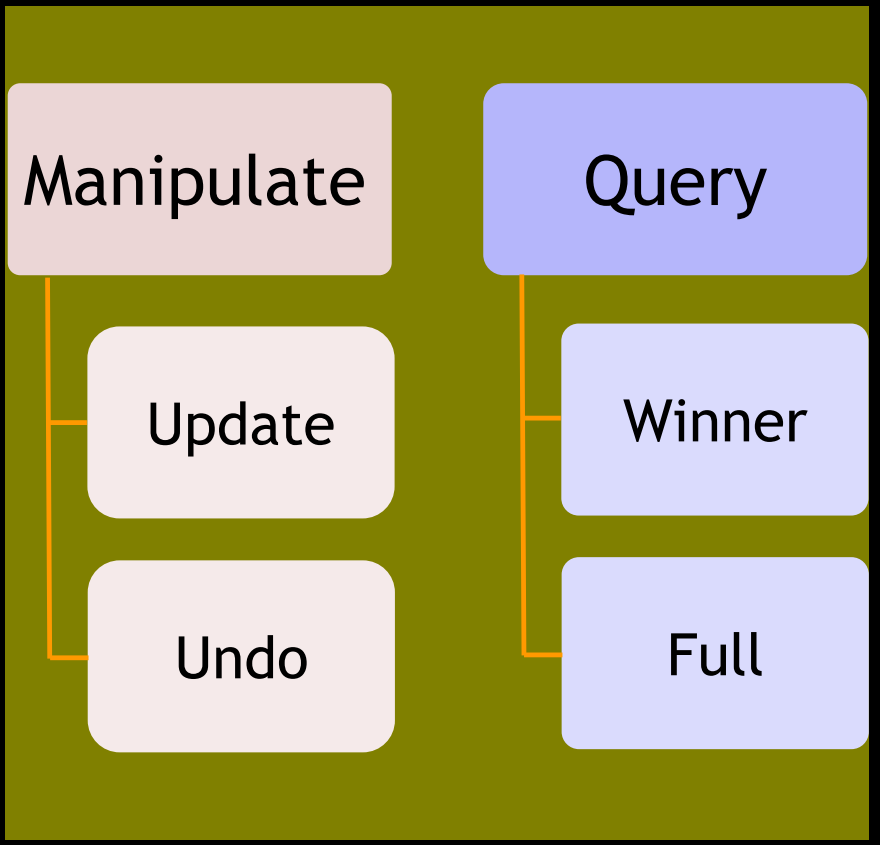
- Kernel for each
  - Mini-Max, Alpha-Beta
- Board C++ class
  - Rules specific
- Games

3D Tic-Tac-Toe | Connect-4 | Reversi



Board



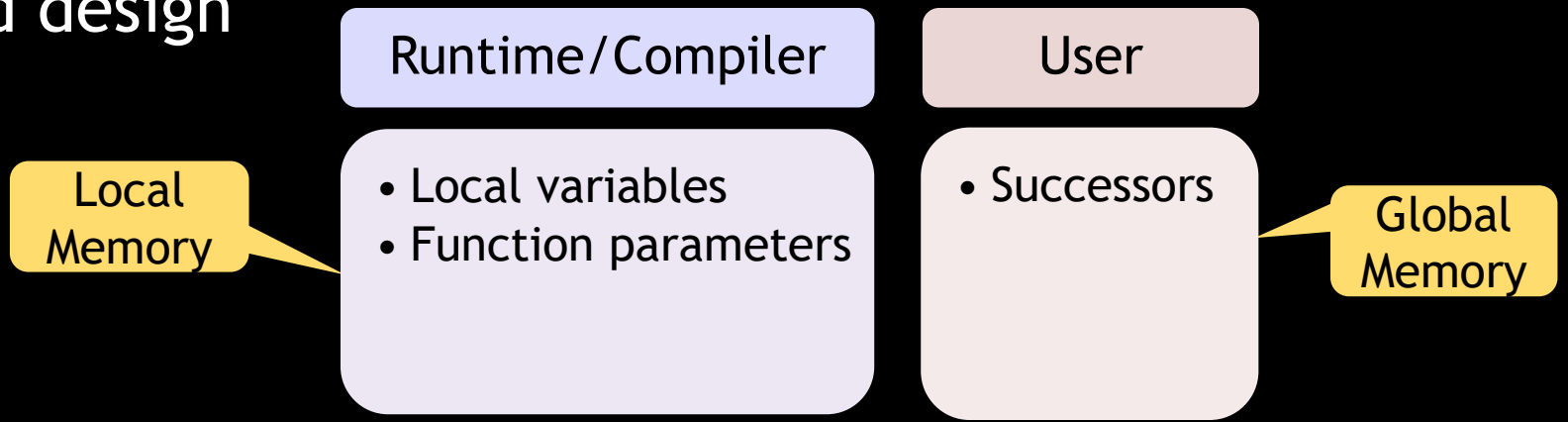


Stack

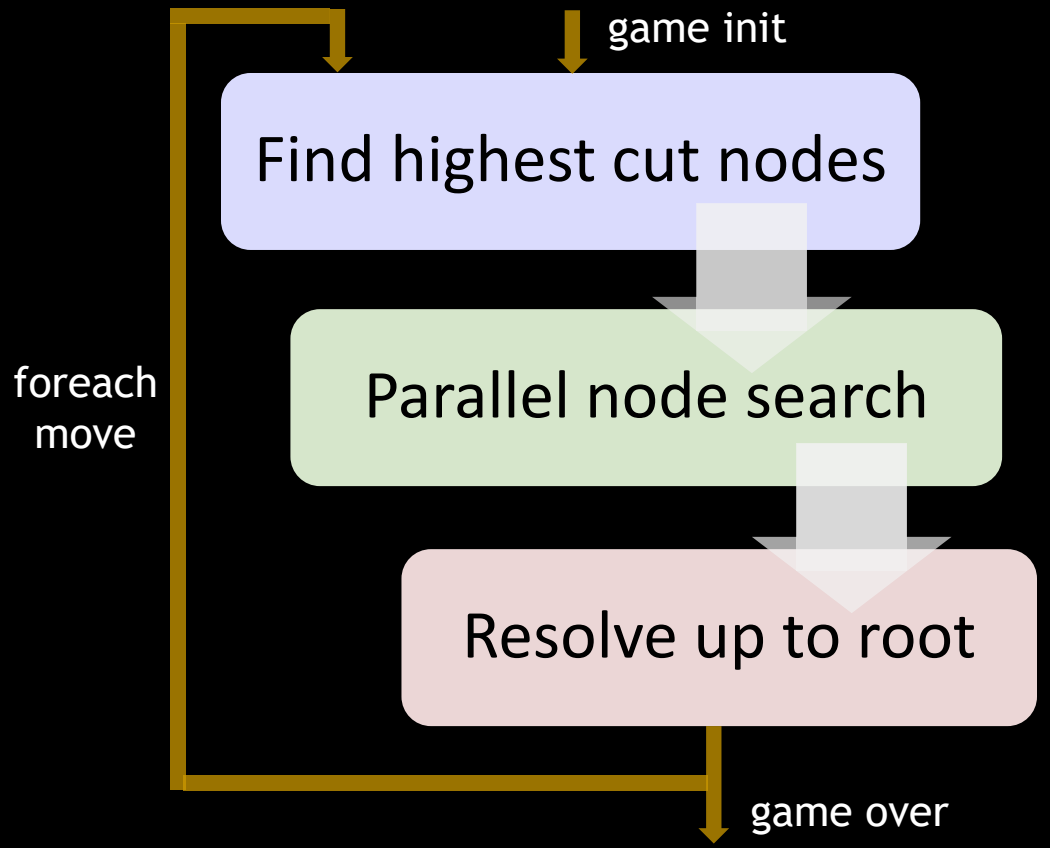
- Recursion depth >1000
- Greedy allocation

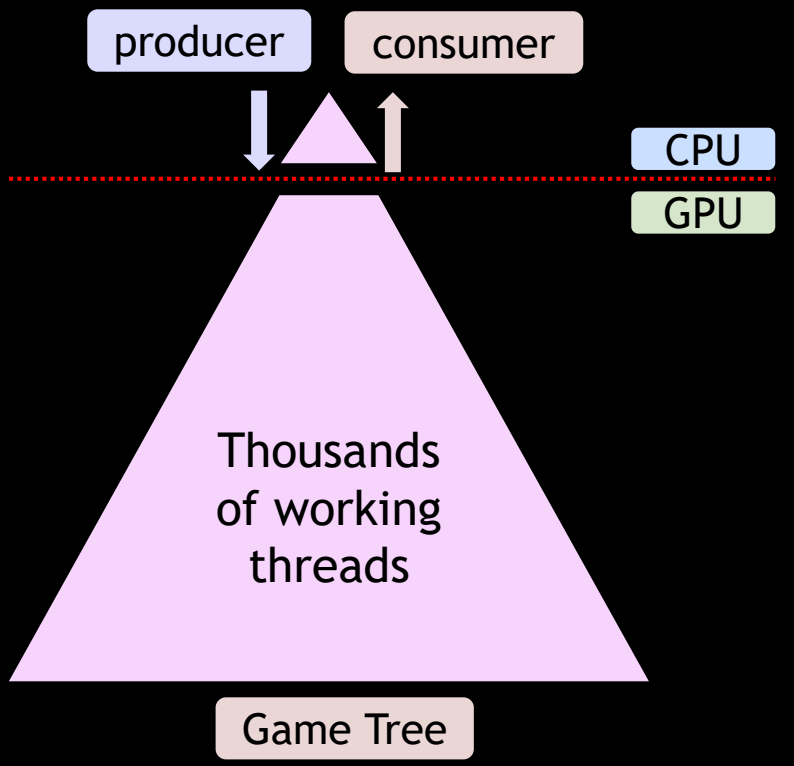
$$StackBytes/Thread * SM\ \# * MaxWarps/SM * Threads/Warp$$

- Hybrid design



Split





Shared αß

Kernel global scope

Check private αß

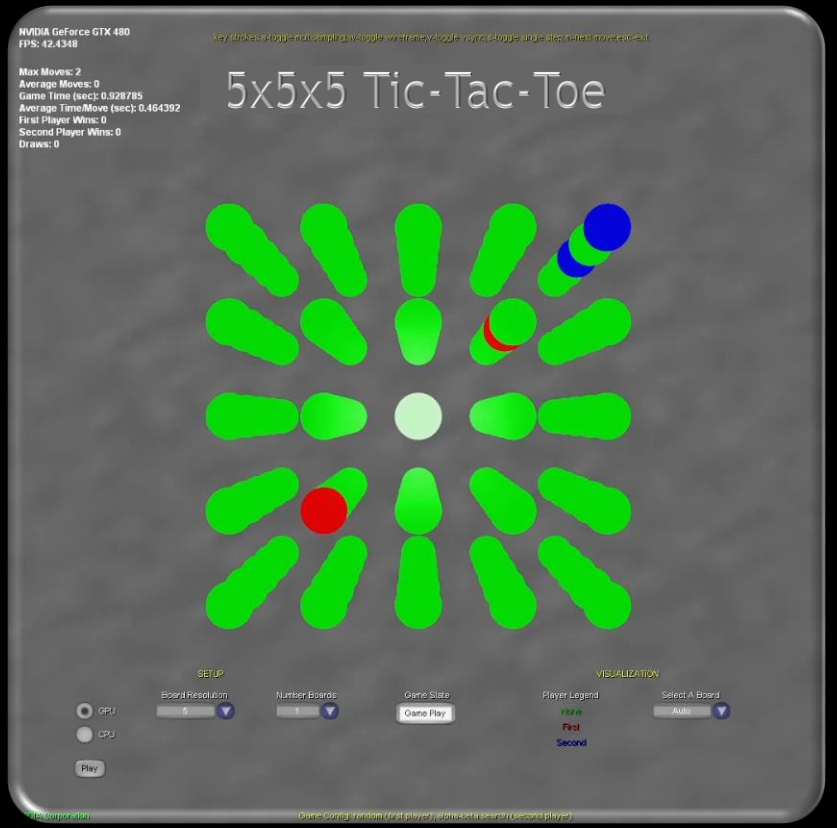
```
__device__ int galpha, gbeta;

__device__ void
resolve(int alpha, int beta)
{
  if(alpha ≤ galpha) alpha = galpha;
  else atomicMax(&galpha, alpha);

  if(beta ≥ gbeta) beta = gbeta;
  else atomicMin(&gbeta, beta);
}
```

Global atomic update

Limitations

- Stack allocation
  - Bounds parallelism
- Split constraints

Depth	Tic-Tac-Toe Threads		
	3x3x3	4x4x4	5x5x5
1	650	3906	15252
2	15600	238266	1860744



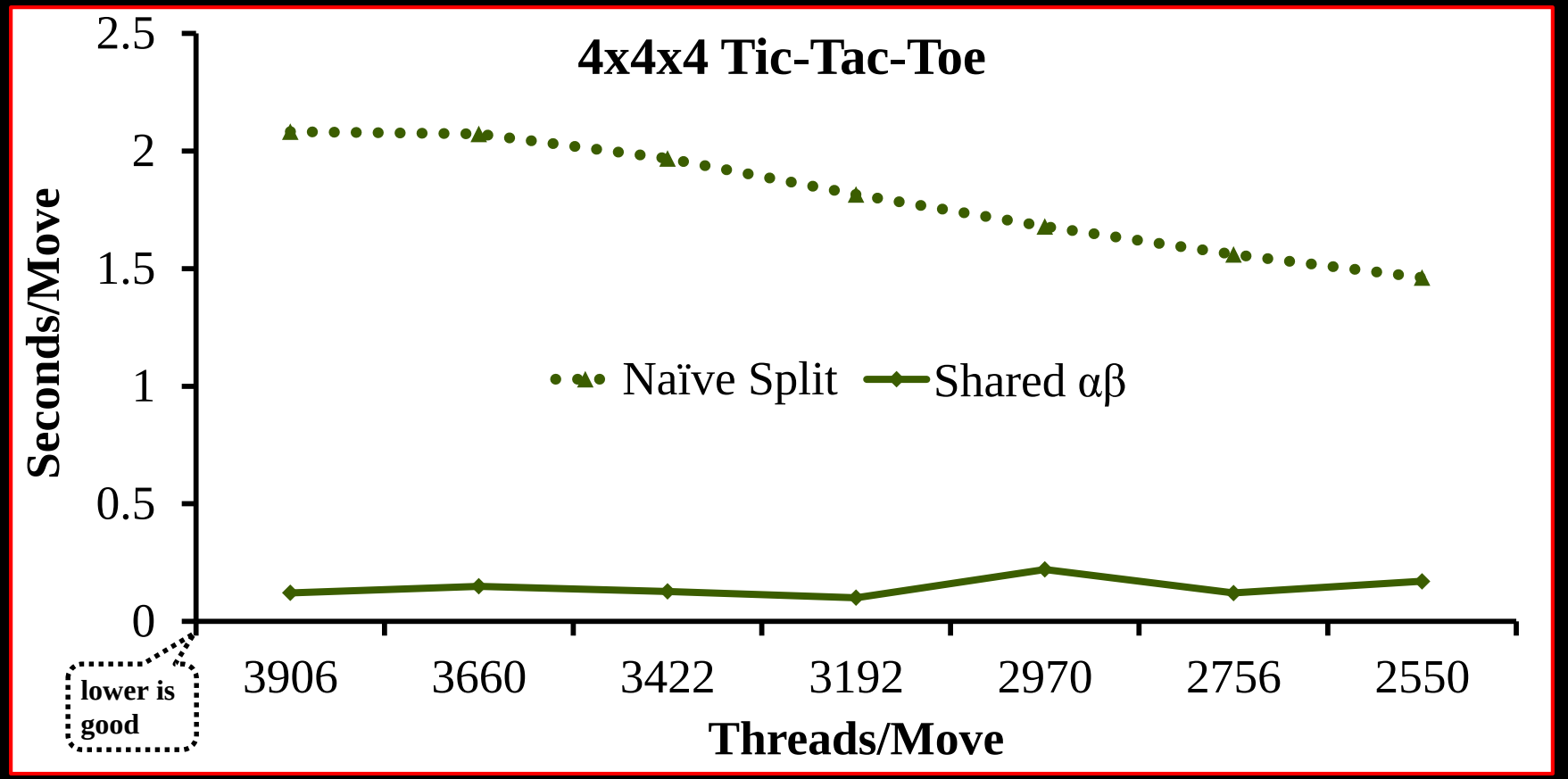
Methodology

- CUDA Toolkit 3.1, Windows
- Processors

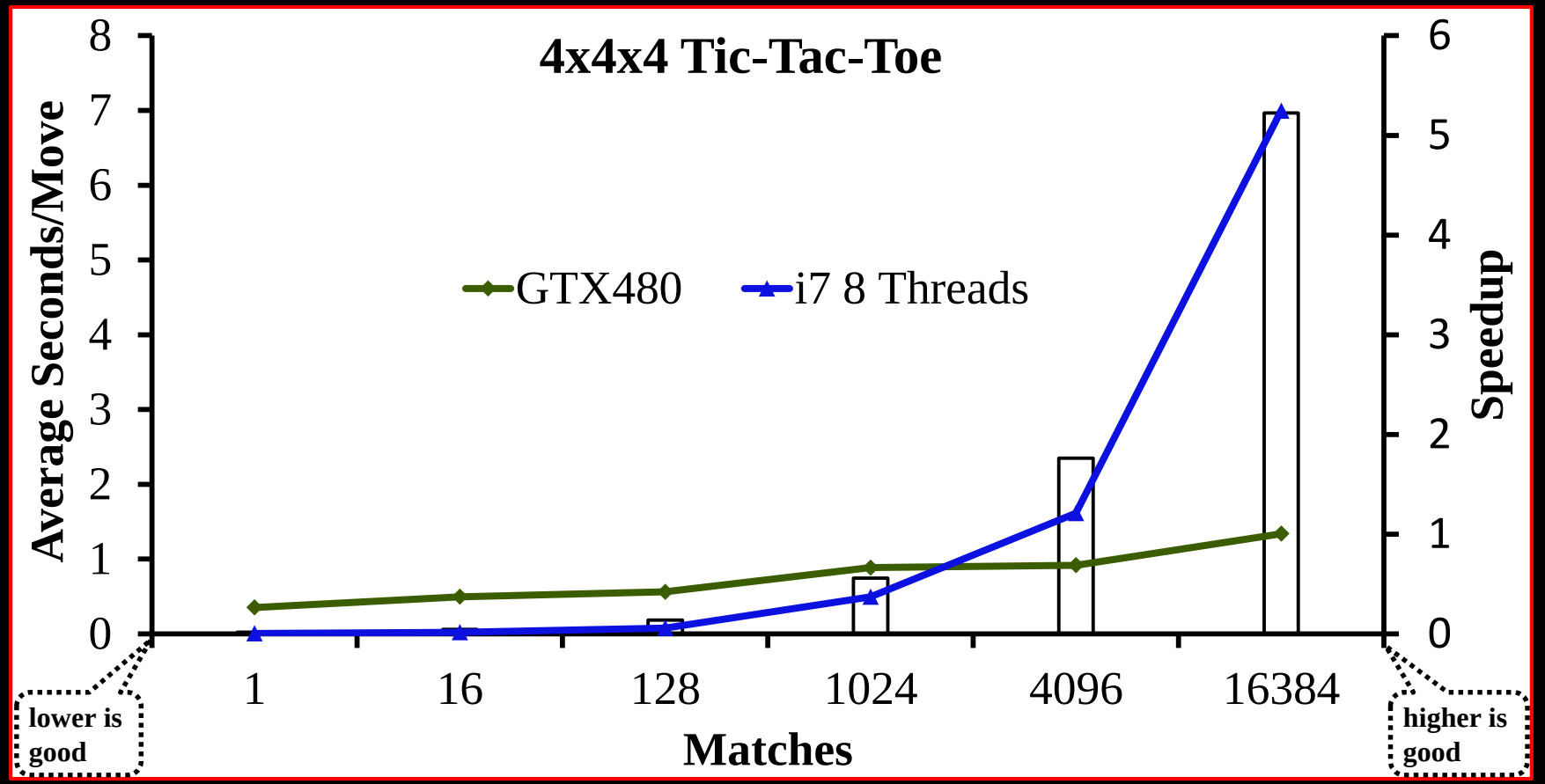
GPU	SMs	Warps/SM	Clocks(MHz)	L1/Shared (KB)	L2(KB)
GTX480	15	2	723/1446/1796	48/16	640

CPU	Cores	Clocks(MHz)	L1/L2 (KB)
I7-940	8	2942/(3*1066)	32/8192

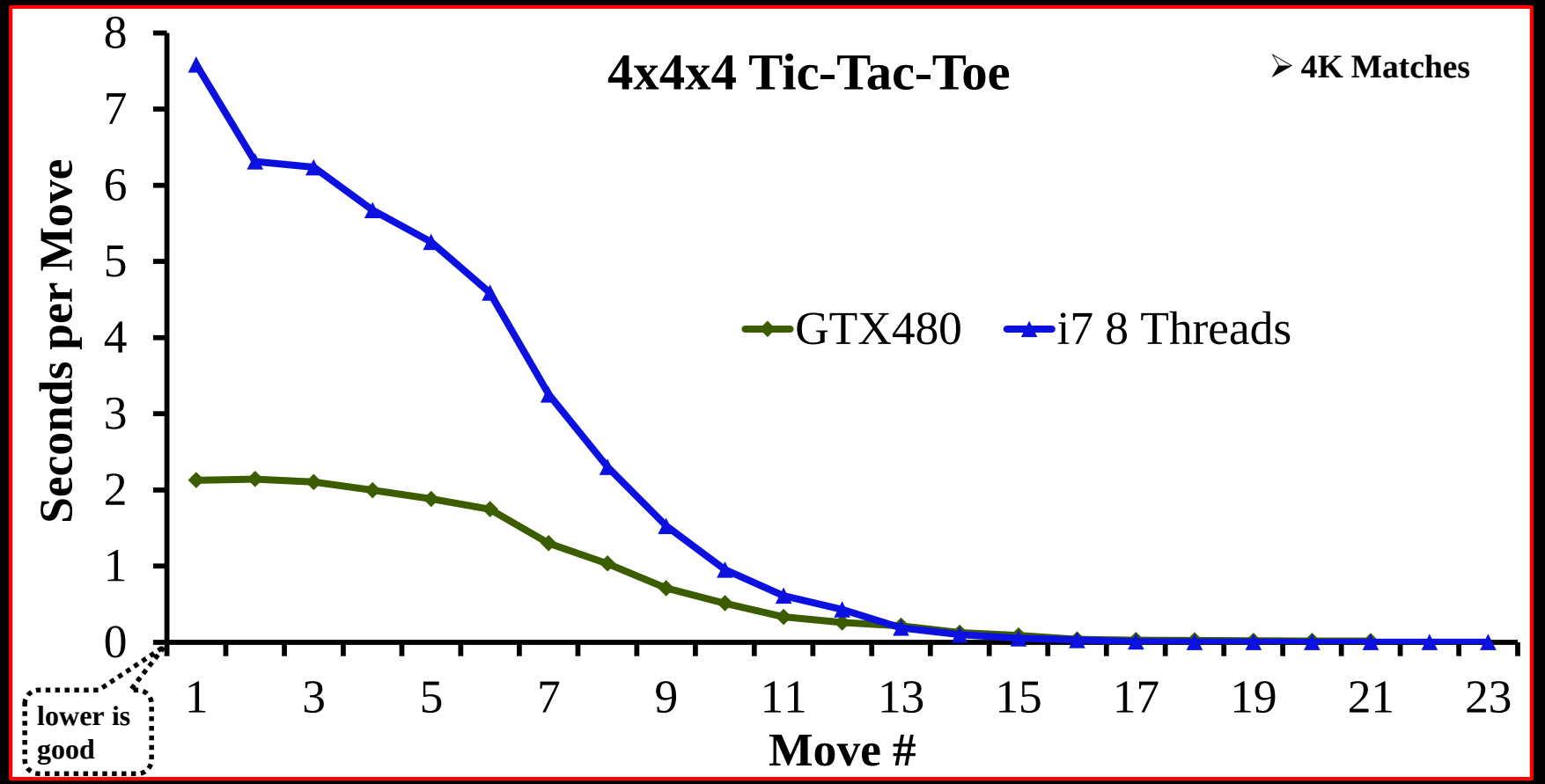
Single Game



Simultaneous Matches

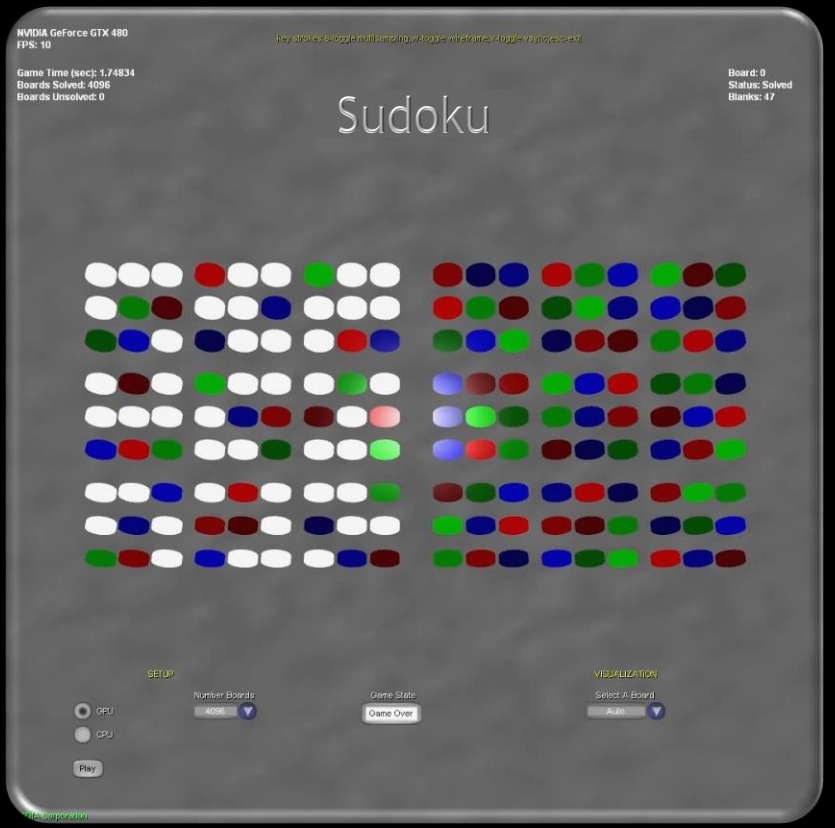


Game Analysis



Future Work

- Data packing
- Backtracking search
- Sudoku, toy game
  - Generator, solver
- Multi recursion



GPU Performance

Metric	Game	Dimension	Speedup
Shared αß vs. Naïve Split	Tic-Tac-Toe	4x4x4	13.37X mean
Simultaneous Matches vs. CPU	Tic-Tac-Toe	4x4x4	5.22X @ 16K
	Connect-4	7x6	6.26X @ 32K
	Reversi	8x8	5.96X @ 16K

Summary

- Efficient hybrid stack
- Dynamic parallelism
- Tegra, Tesla solution
- 3D Chess on GPU!

	Deep Blue	Tesla
$/(Moves/Sec)	0.5	0.02

Courtesy freegames4all

Thank You!

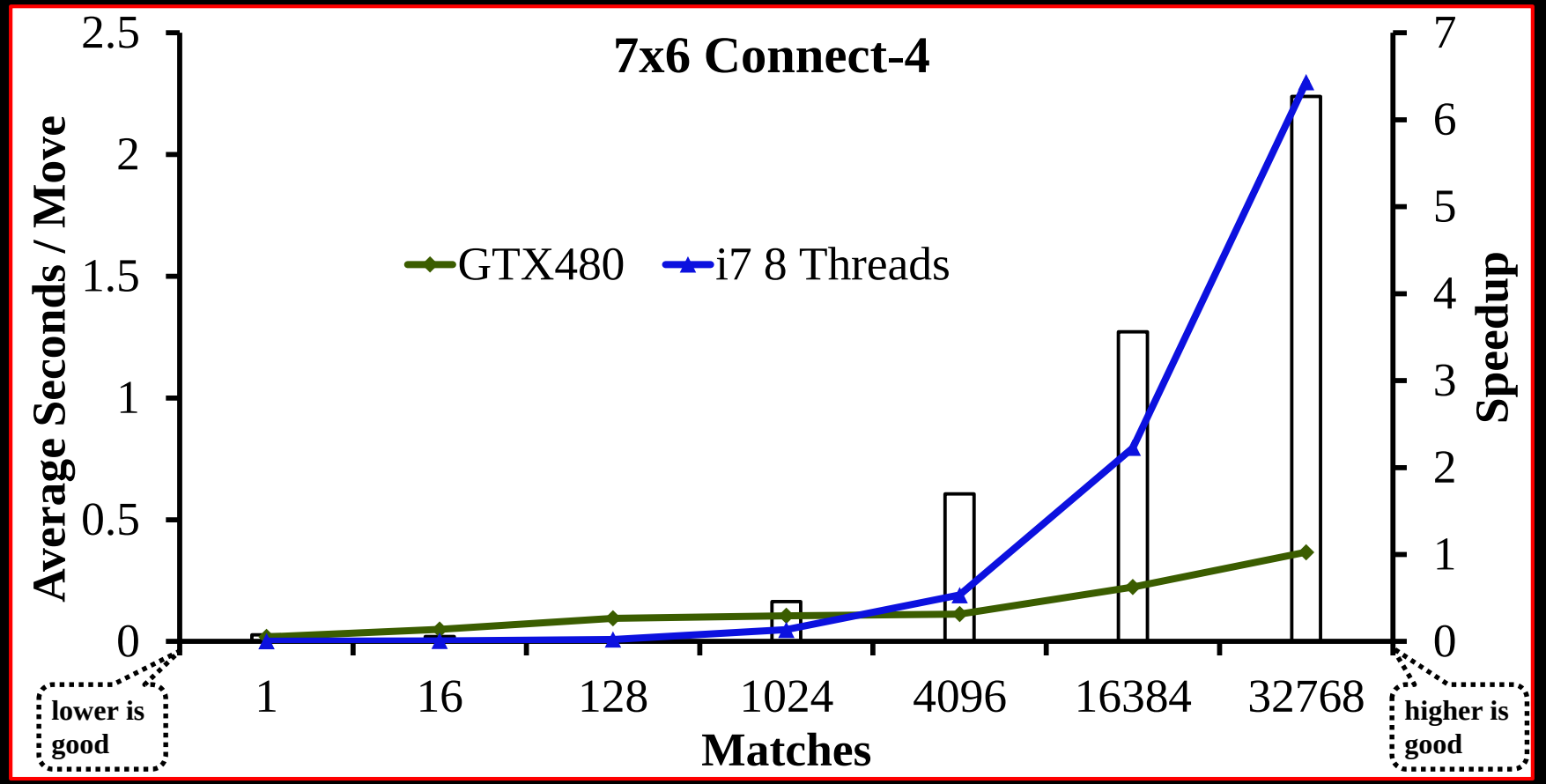
Questions?

Info

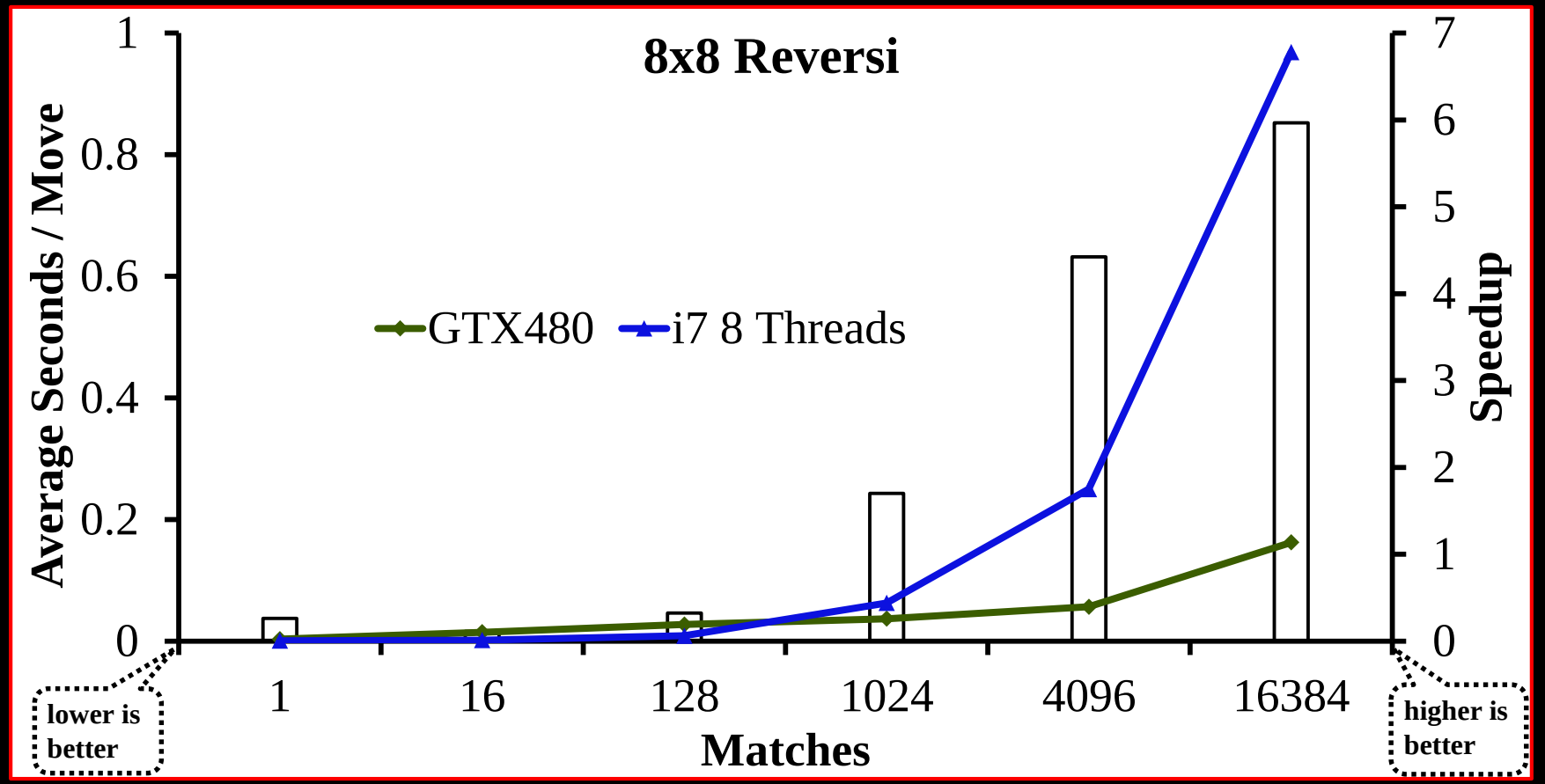
- Base
  - http://developer.nvidia.com
- GPU AI
  - Technology Preview
- Toolkit
  - CUDA Zone
- Debugger
  - Parallel Nsight

Backup

Simultaneous Matches (1)



Simultaneous Matches (2)



Simultaneous Puzzles