# Parallel asynchronous algorithm for the search of connected components on multiprocessors

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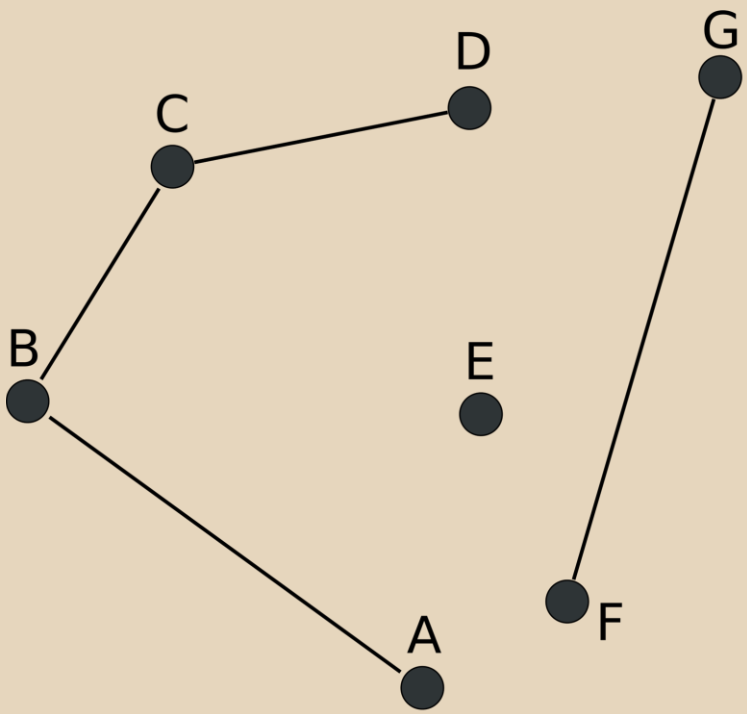
# Connected component




- In graph G, two vertices *u* and *v* are called **connected** if G contains a path from *u* to *v*
- A graph is **connected** when any two vertices are connected
- A connected component of an graph is a subgraph which any two vertices are connected, and which is connected to no additional vertices in the supergraph

# Graphs

**Types of graphs:**

- rmat-n ($2^n$ vertices)
- ssca2-n ($2^n$ vertices)
- grids + single vertexs
- linear

Graphs are given in CSR format

# System

Testing on:

- *Intel Xeon E5-2690 2.90GHz 2x8 ядер*
- *Intel Xeon Phi 7110X*

Compilation keys in icpc:

- *O3 -ipo -march=native*

Core affinity:

- *Export KMP_AFFINITY=compact*

# Algoritm Shiloach-Vishkin(SV)

Array D[1..n], where D[i] is the component's number to which "i" is belong.
Initially D[i] = i.

1) **for** (i, j) ∈ E **do**
   **if**( (D[i] < D[j]) && (D[j] == D[ D[j] ]) ) **then** D[ D[j] ] = D[i];

2) **Pointer Jumper**
   **for** (i, j) ∈ E **do**
   **while**( D[i] != D[ D[i] ] ) **do** D[i] = D[ D[i] ];

3) **if(** D not change) **then** exit;
   Otherwise, go to 1.

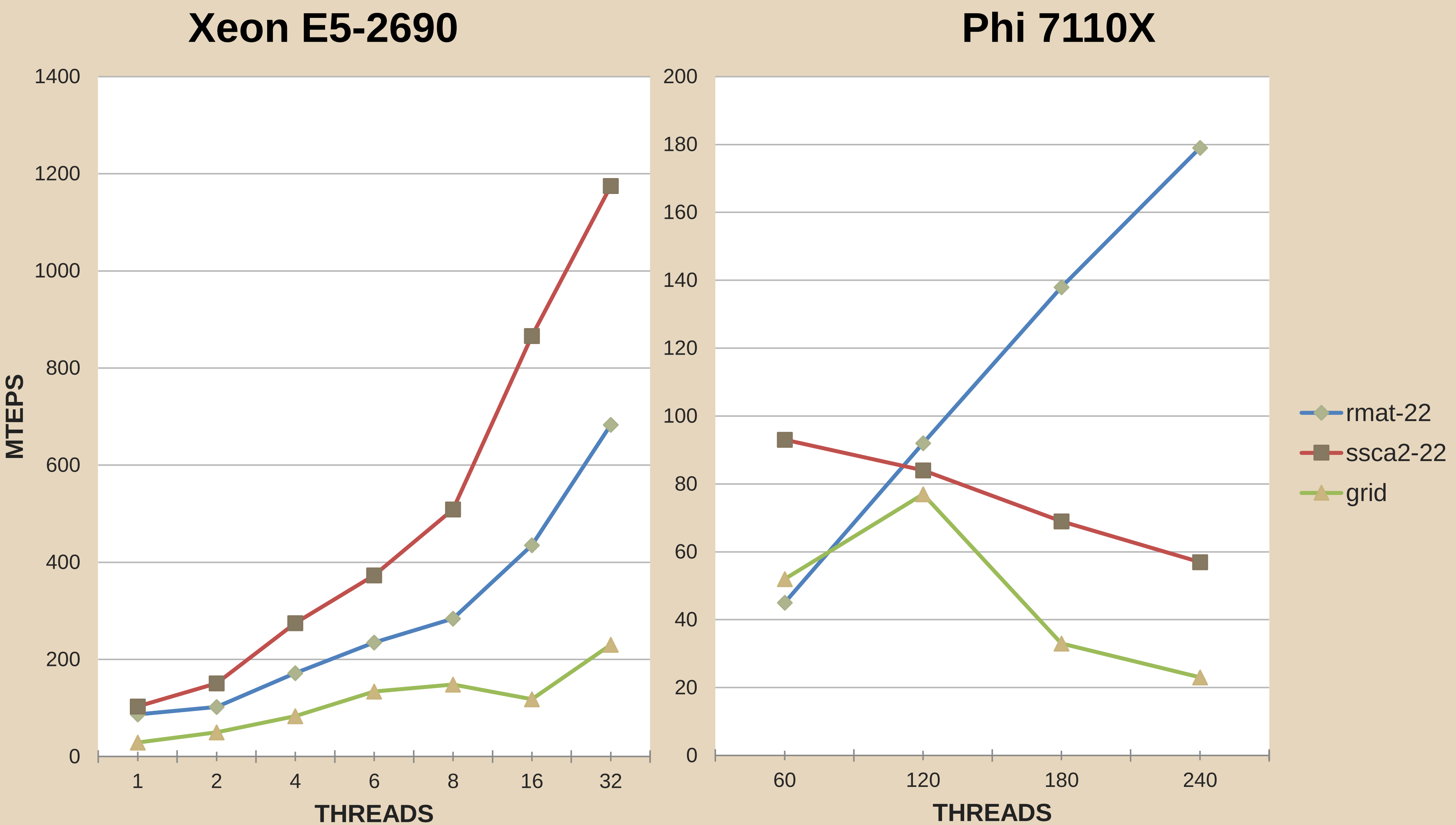
# Algorithm Shiloach-Vishkin(SV)

+ Scalability

+ Easy to be parallelized
  a. insert openMP pragmas
  b. no dependencies

- Often repeats operations

# Algorithm Shiloach-Vishkin(SV)



# Asynchronous algorithm (ABFS)

Dynamic pool of colors P[1..n]

1) Each thread executes BFS to paint some subgraph in its own color

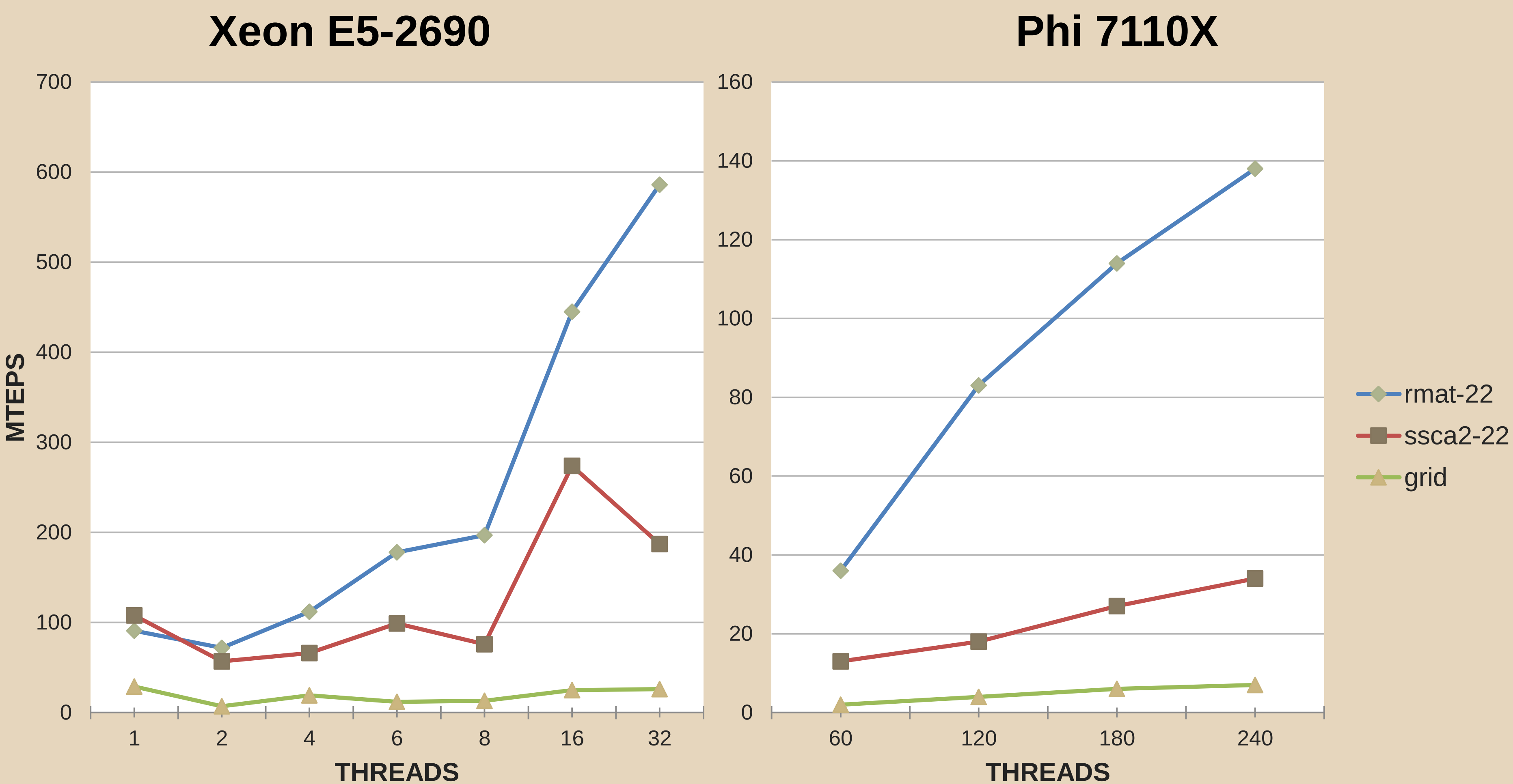
2) Pointer Jumper

3) Coloring (simple loop)

# ABFS(naive)+SV

- ABFS colors large components
  - if thread visits colored vertex, it skips
- SV makes corrections (at the border)

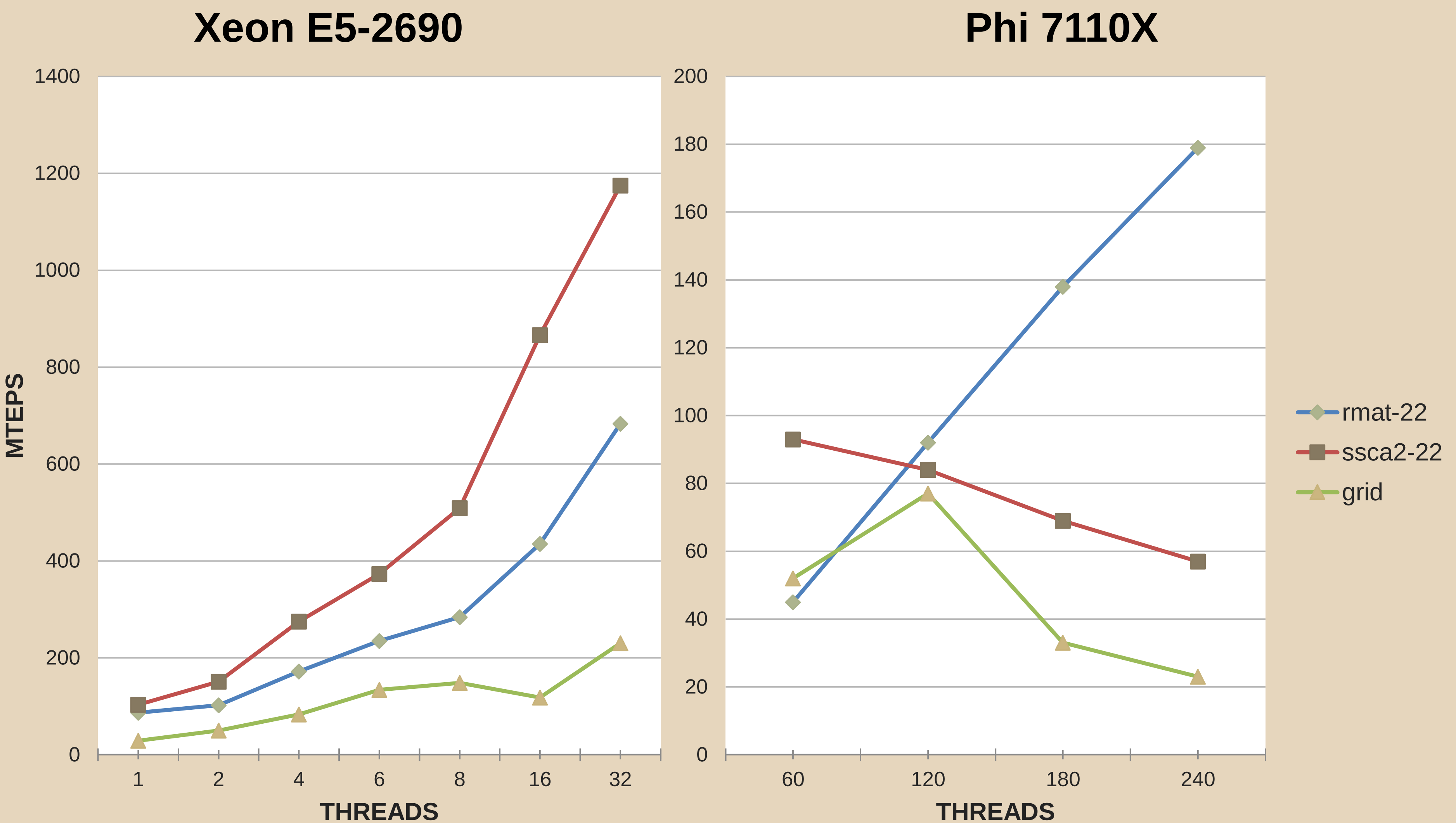
# ABFS(naive)+SV



# ABFS+SV

- ABFS colors large components
  - if thread visits colored vertex and vertex’s color less than thread’s color, then thread change own color
- SV makes corrections (at the border)

# ABFS+SV


Xeon E5-2690
Phi 7110X
MTEPS
0
200
400
600
800
1000
1200
1400
1
2
4
6
8
16
32
THREADS
0
20
40
60
80
100
120
140
160
180
200
60
120
180
240
THREADS
rmat-22
ssca2-22
grid

# PBFS+critical

- Each thread executes BFS to paint some subgraph
  - if thread visits colored vertex and vertex’s color less than thread’s color, then thread change own color
  - collisions are handled in critical sections
- Pointer Jumper
- Coloring

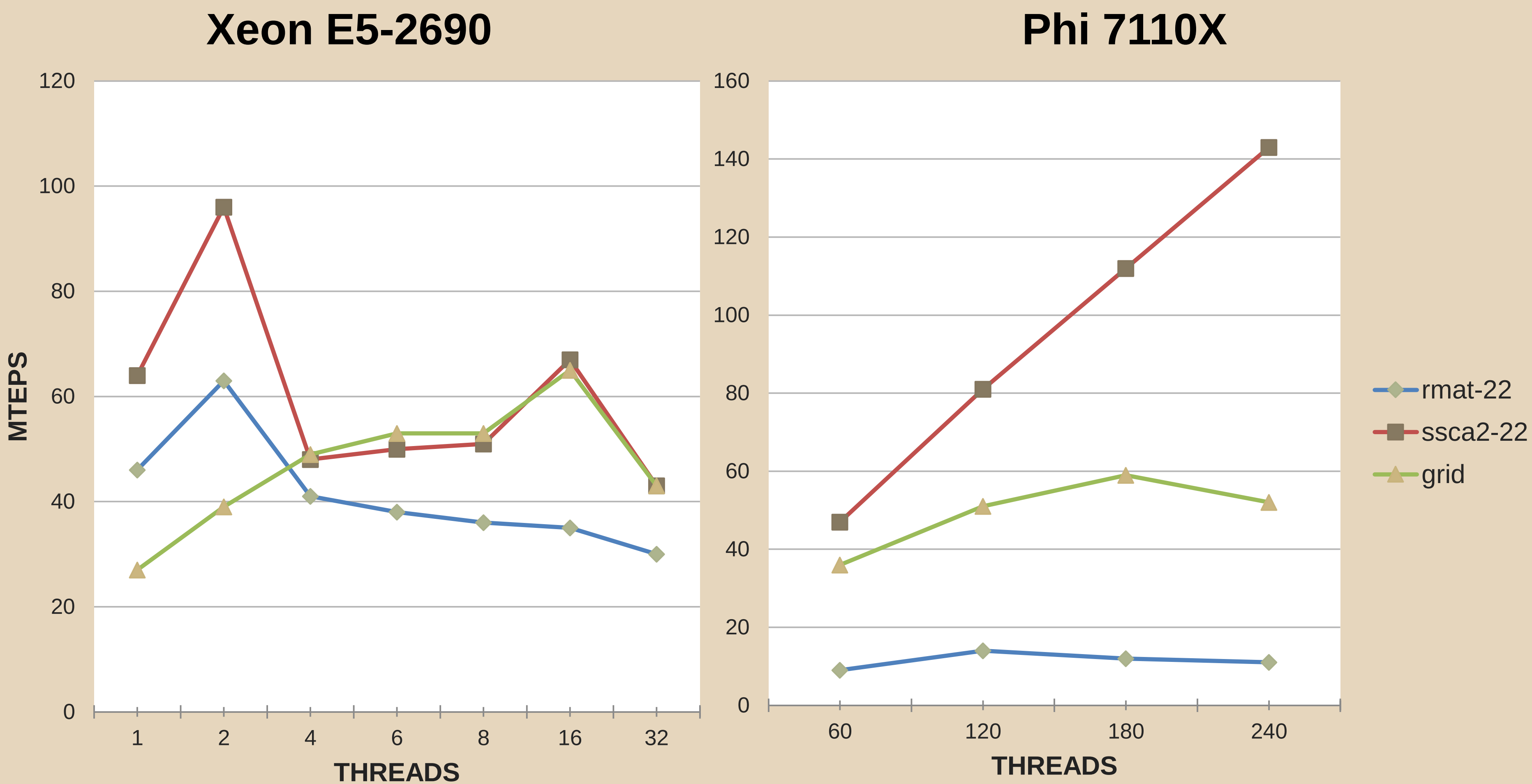
# PBFS+lock free

- PBFS+critical

- Critical sections are replaced on built-in functions:
  *bool __sync_bool_compare_and_swap(...)*

```
do {
   while( old_root != pool[ old_root ] ) old_root = pool[ old_root ];
   while( new_root != pool[ new_root ] ) new_root = pool[ new_root ];
   if( new_root < old_root )
      is_ok = __sync_bool_compare_and_swap( & pool[ old_root ], old_root, new_root );
   else
      is_ok = __sync_bool_compare_and_swap( & pool[ new_root ], new_root, old_root );
} while( ! is_ok )
```

# PBFS+lock free

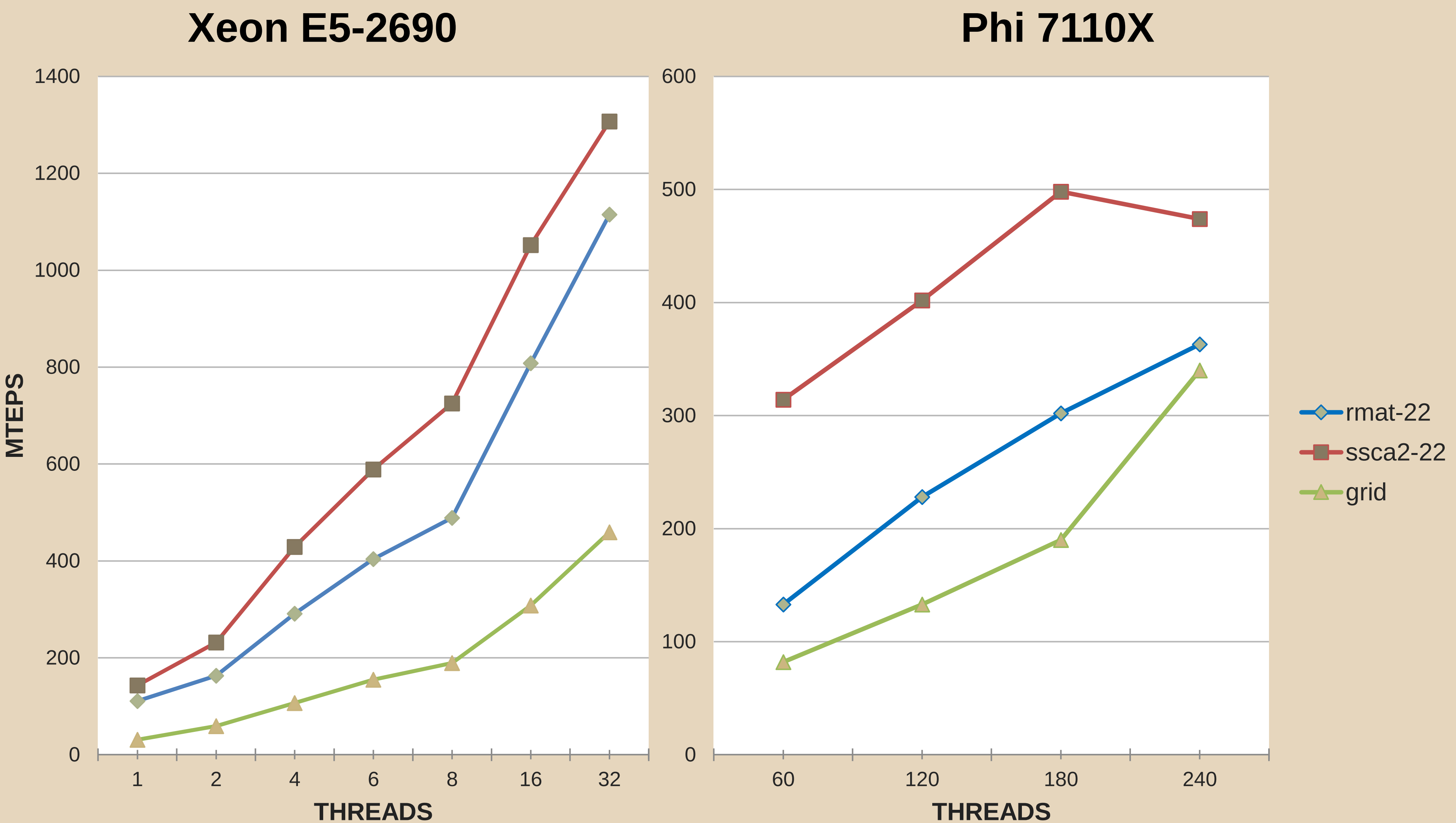



*due to the low performance of this algorithm will not be considered further

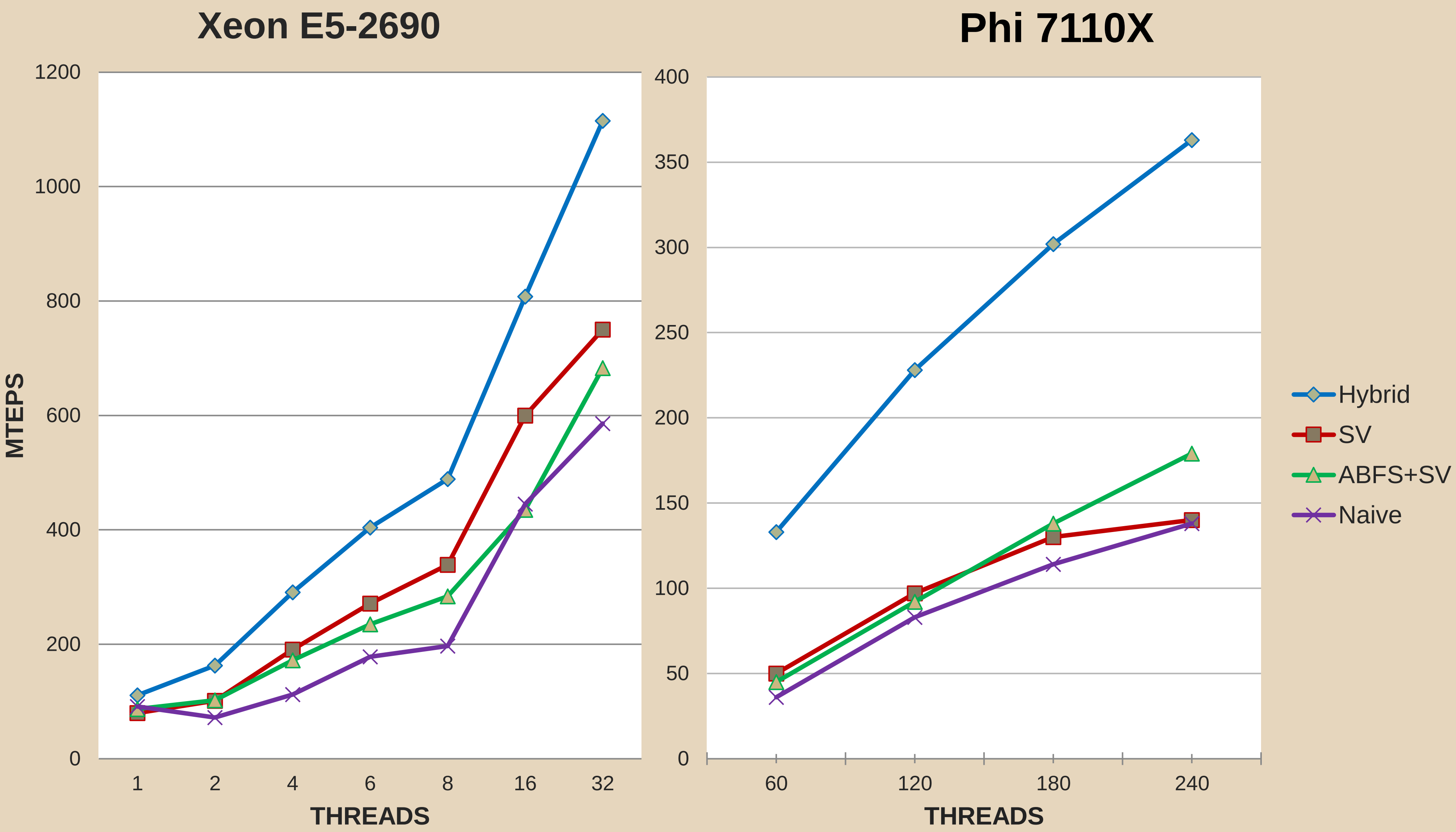
# ABFS+SV - Hybrid

- ABFS colors large components
  - if thread visits colored vertex and vertex's color less than thread's color, then thread change own color
- A first phase of SV makes corrections (at the border)
- Pointer Jumper
- Coloring

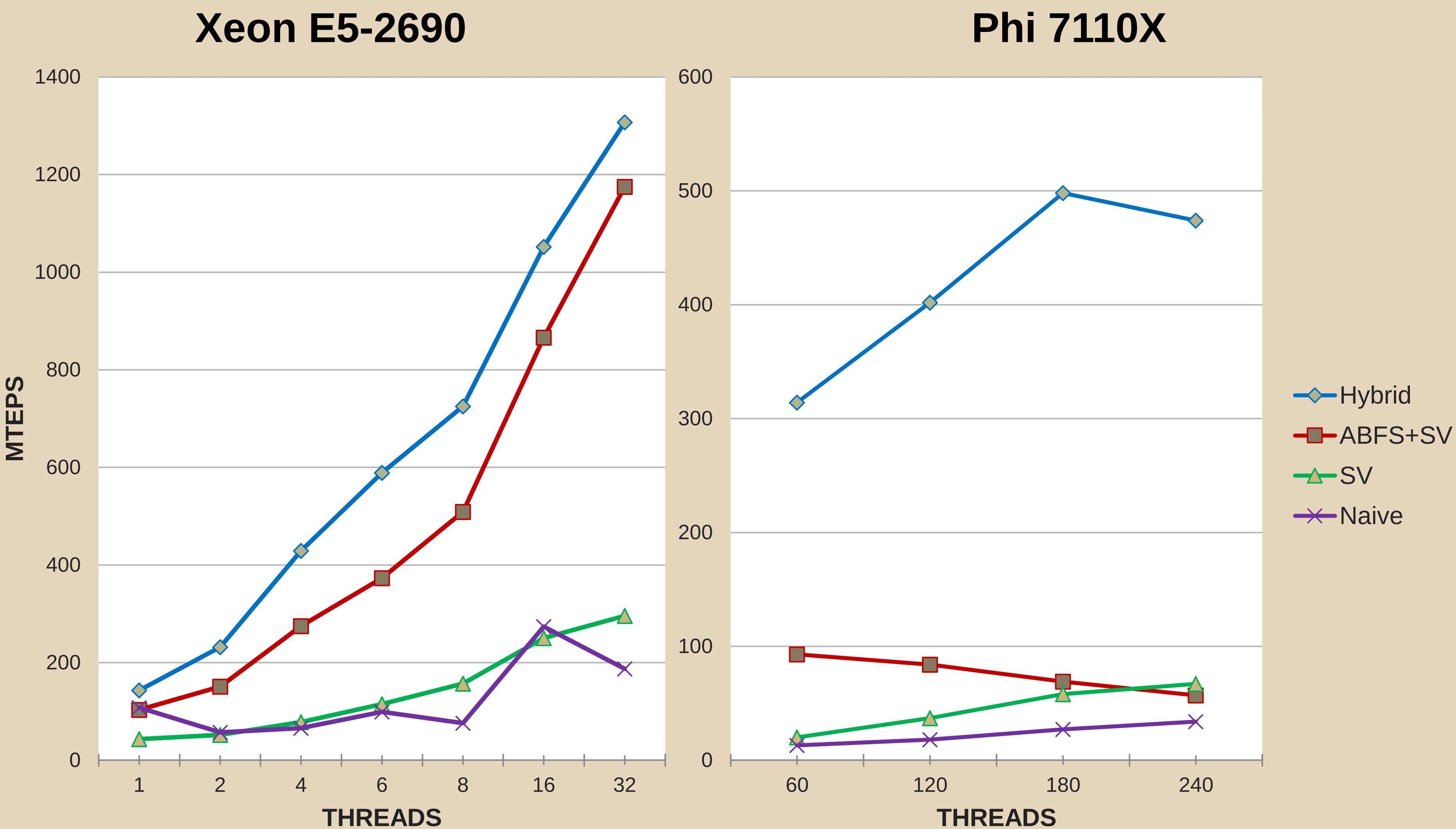
# ABFS+SV - Hybrid



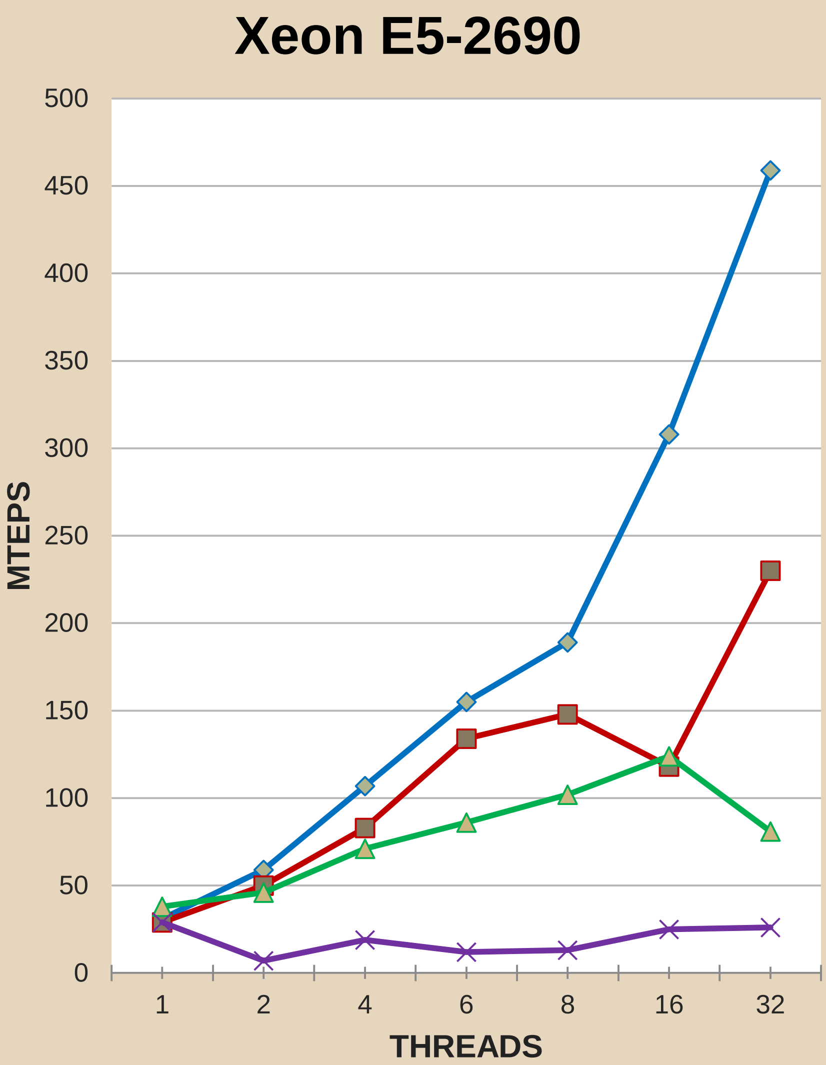
# Comparison of algorithms on rmat-22

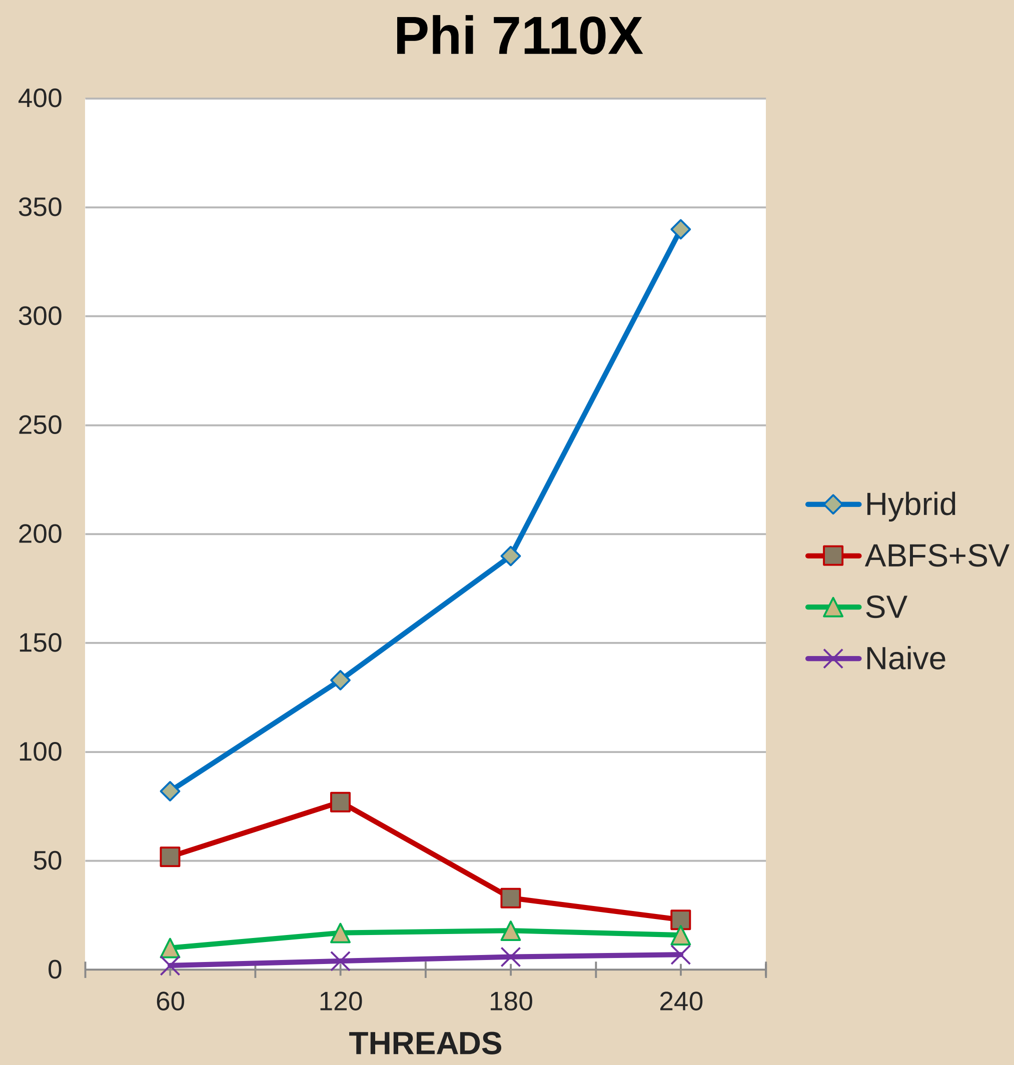


# Comparison of algorithms on ssca2-22



# Comparison of algorithms on grid



# Perspective

- Optimization under Xeon Phi
- Further improvements of the algorithm
  - early stop at the first stage of the ABFS
  - using block of colors by thread