Evaluation of Active Graph Applications on the MTA-2

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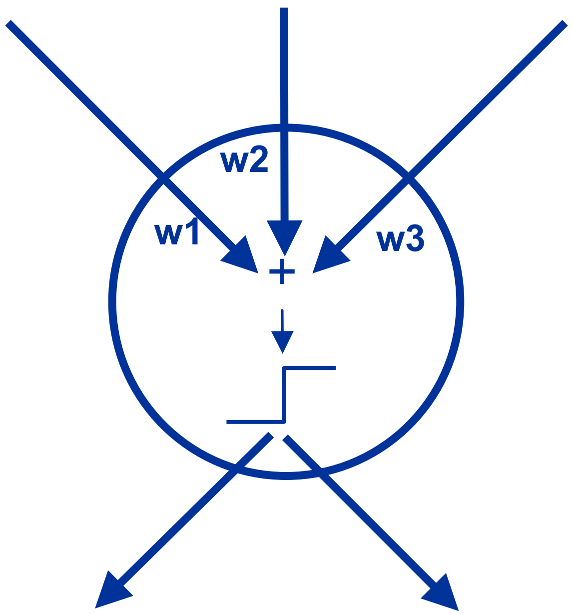
Summary

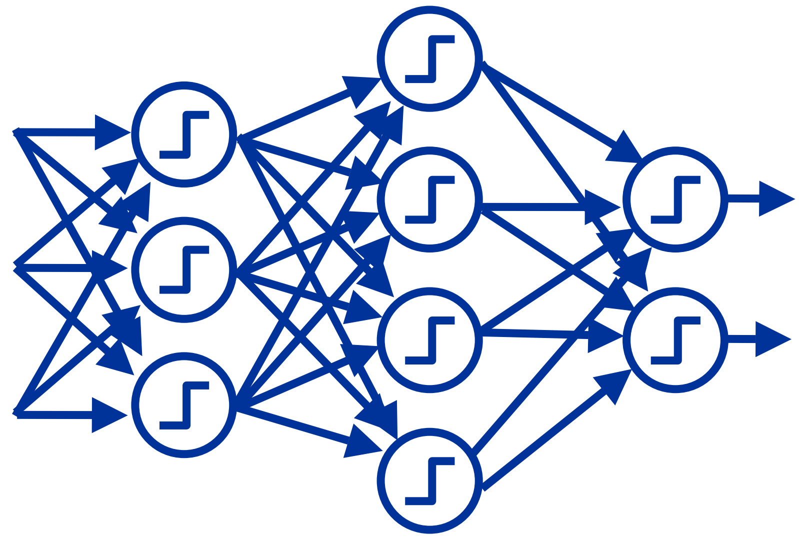
- Goals
  - Examine massively-parallel lightweight multithreading for modeling systems of intercommunicating agents
  - Look at tradeoffs between programming productivity and execution efficiency for active graphs on MTA-2
- Outline
  - Definitions and example applications
  - Representation of active graphs
  - Experiments and results
  - Conclusions and future work

Active Graphs

- Definition
  - Each node (possibly edge) tied to a distinct thread
  - Flow of data through producer/consumer relationships between threads
- Thread state
  - input mailboxes
  - working registers
  - pointers to upstream/downstream nodes
- Key issues
  - exploiting parallelism
  - managing synchronization

Neural Net



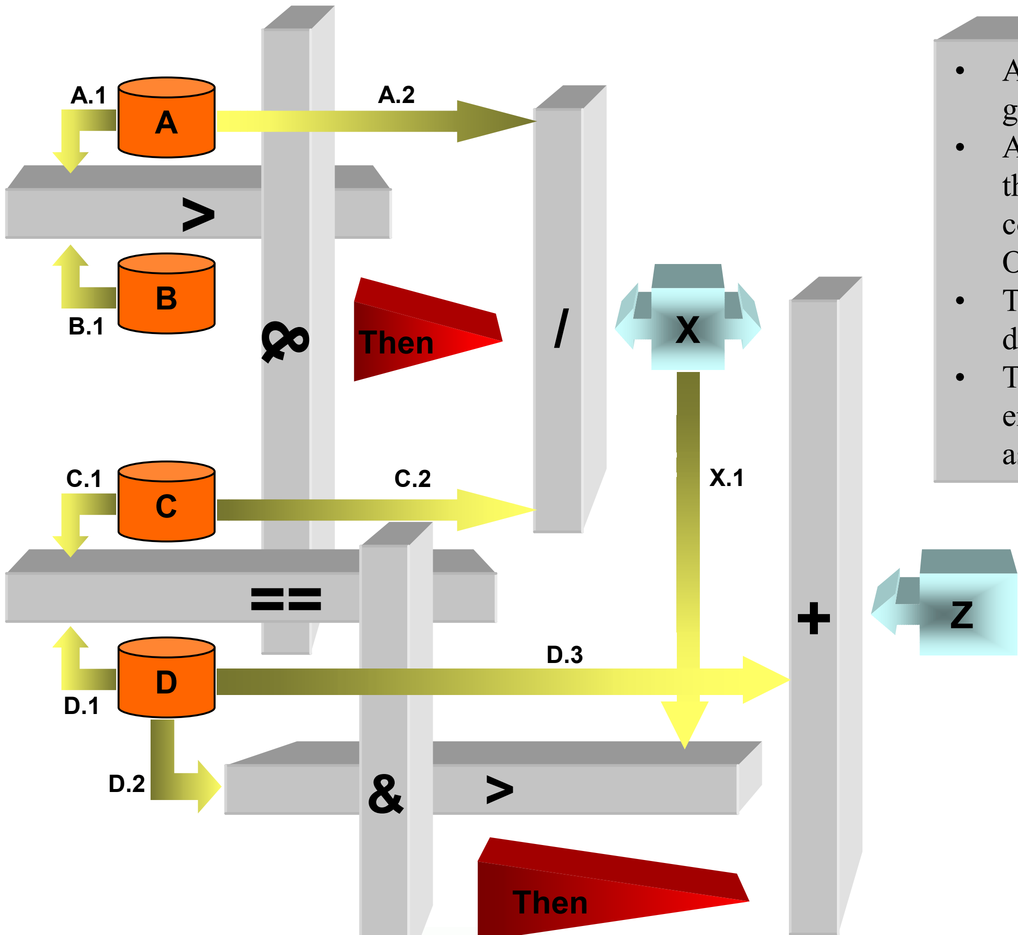


Neural Net

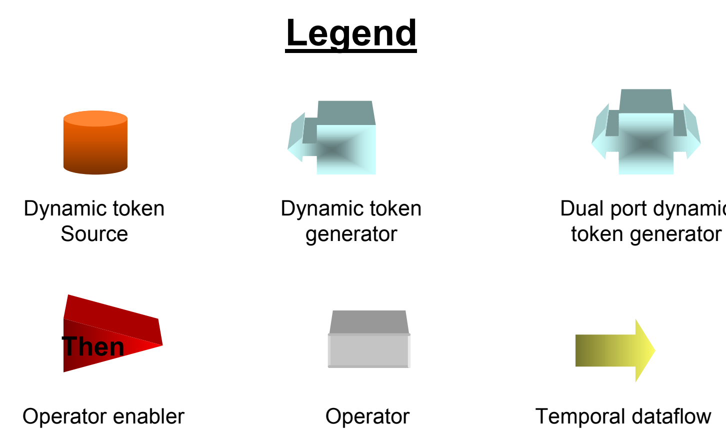
Shine: Spacecraft Health Inference Engine

Rule 1:
If Sensor A > Sensor B & Sensor C == Sensor D
then Var X = Sensor A / Sensor C

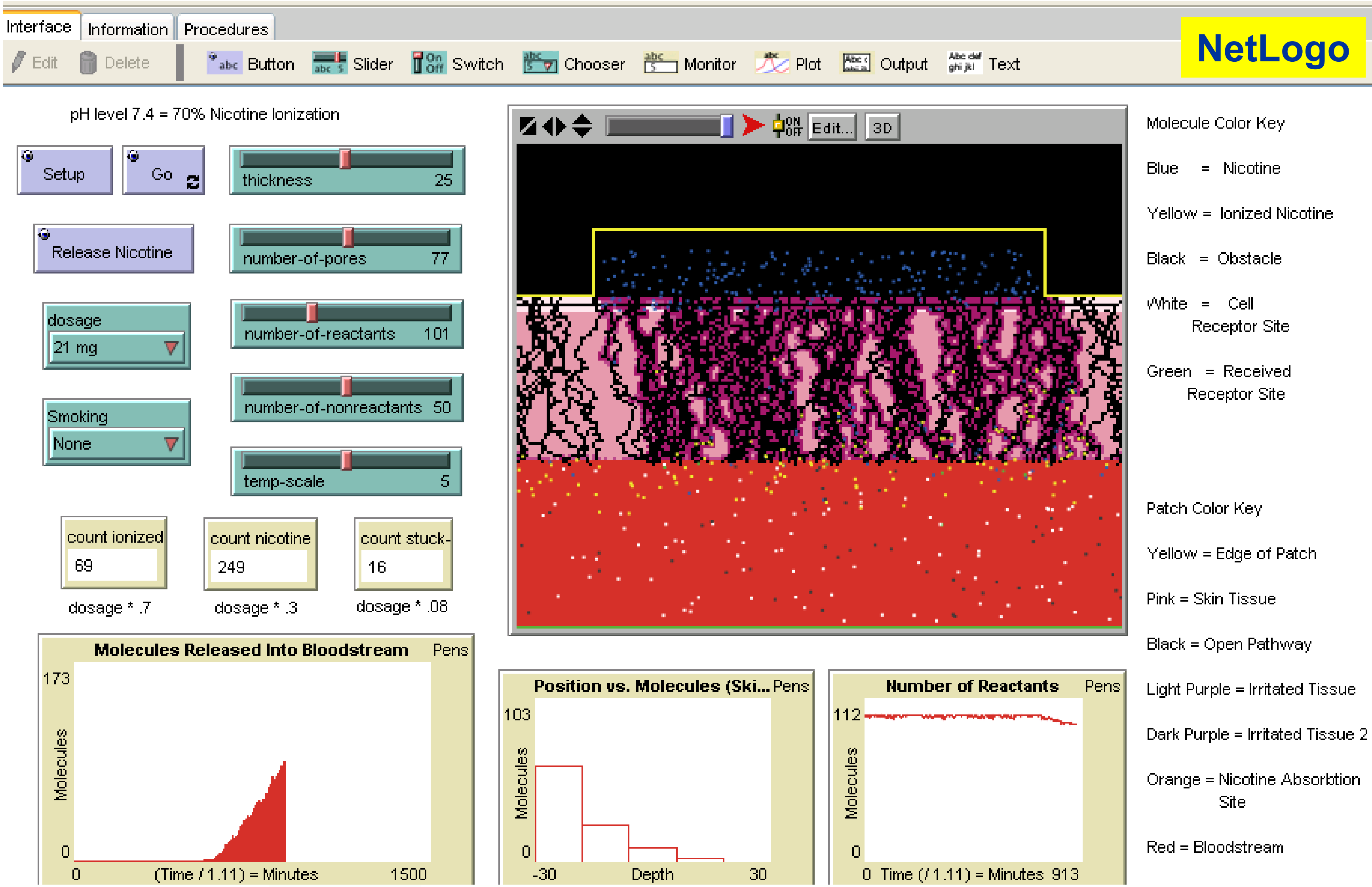
Rule 2:
If X > Sensor D & Sensor C == Sensor D
then Var Z = Var X + Sensor D



- All rules are analyzed respect to one another for all possible global interactions with maximal sharing.
- A sophisticated mathematical transformation, based on graph-theoretic data flow-analysis is introduced, that reduces the complexity of conflict-resolution during the match cycle from $O(n^2)$ to $O(n)$.
- The underlying structure is mapped into temporally invariant dataflow elements.
- The final representation is either executed in a debugging environment or translated to a variety of target languages such as ADA, C and C++.



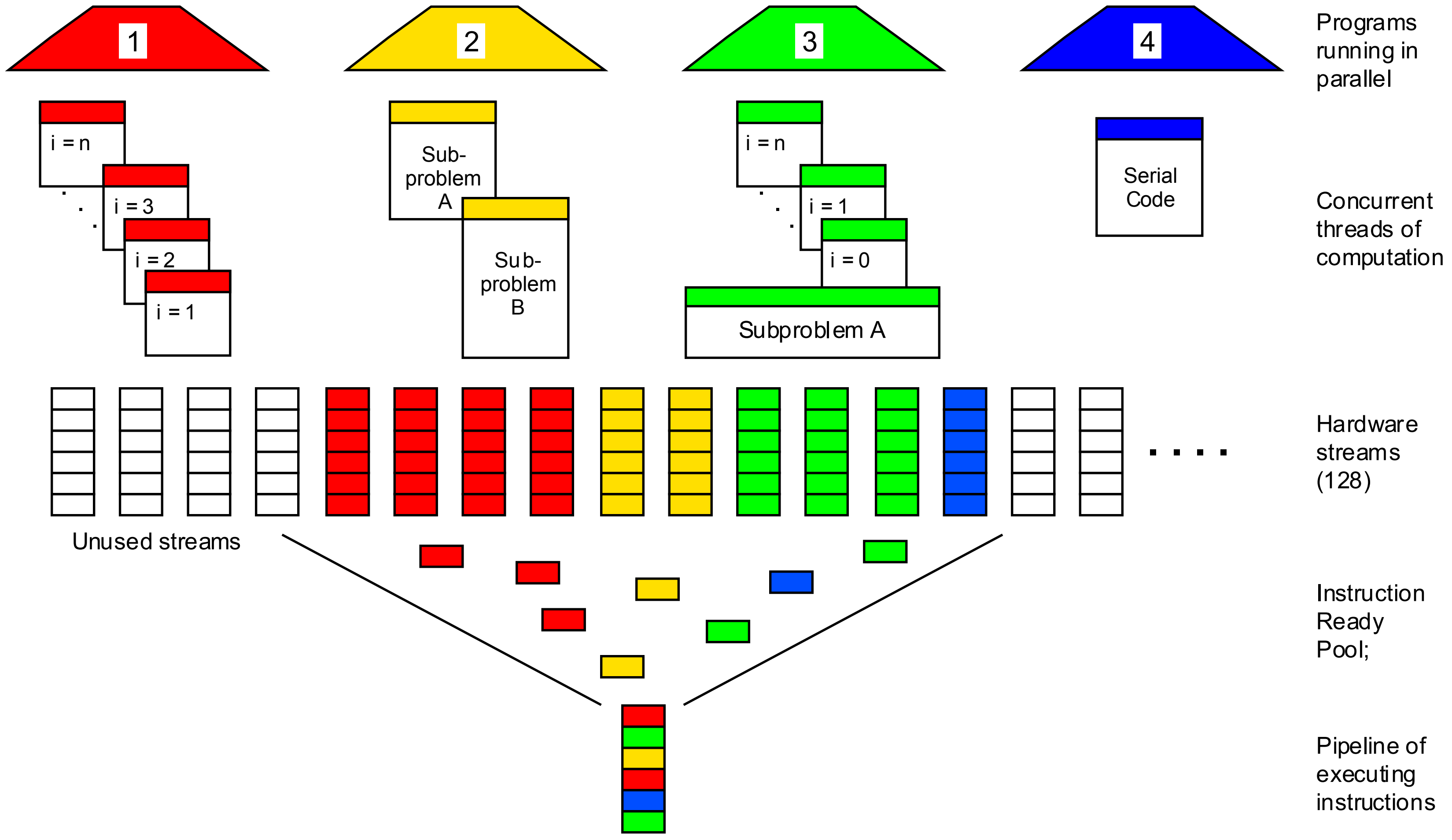
Agent-Based Simulation



MTA Threads

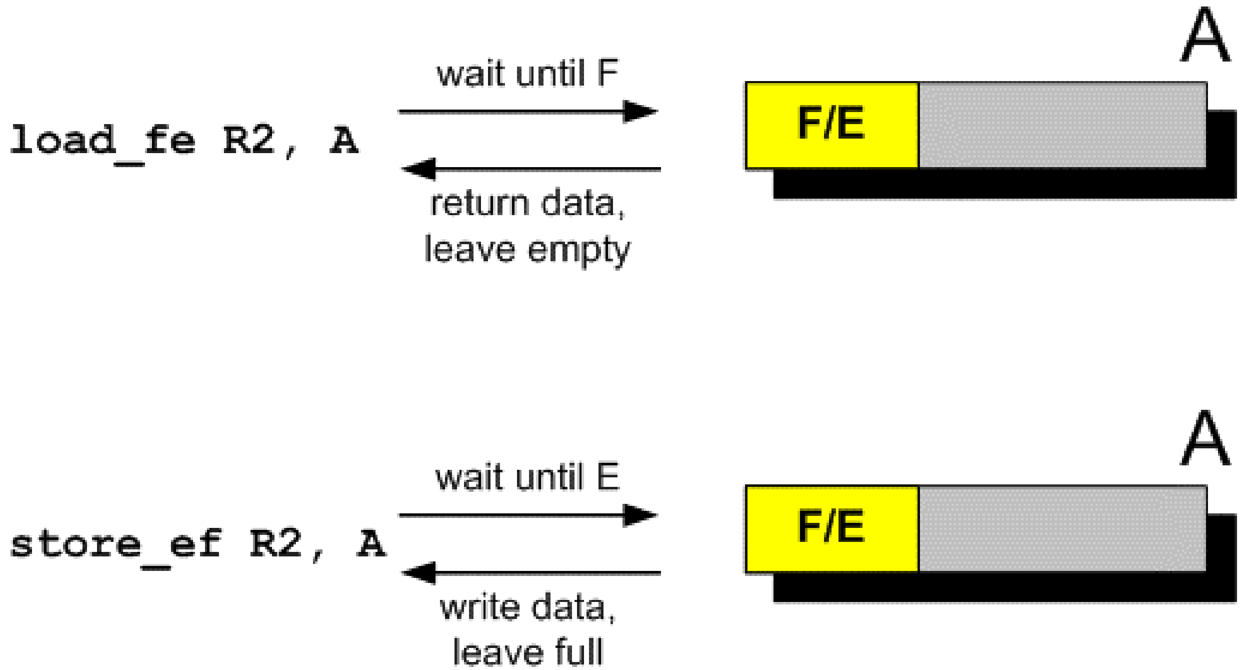
- Very lightweight; managed by compiler and runtime
  - Thread creation, termination, synchronization, and scheduling are performed by user space library code
- Runtime requests OS to add processors
- Thread virtualization
  - Application is coded without knowledge of stream count
  - Runtime migrates thread state between memory and stream
- Implicit creation by complier and user directives
- Explicit creation using future statement

Threads and streams



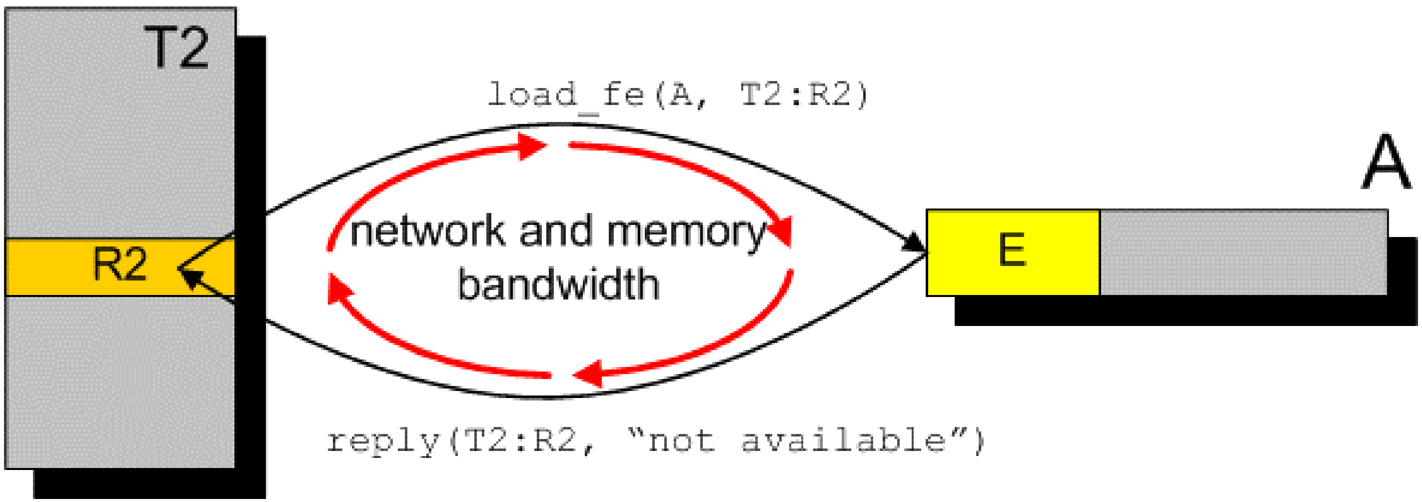
Full/Empty Semantics

- F/E status of a location influences load/store behavior and loads/stores can modify F/E status.
  - Loads/stores can synchronize on F/E.
  - Cheap and abundant synchronization operations.
  - Prior MTA experience implementing f/e semantics.



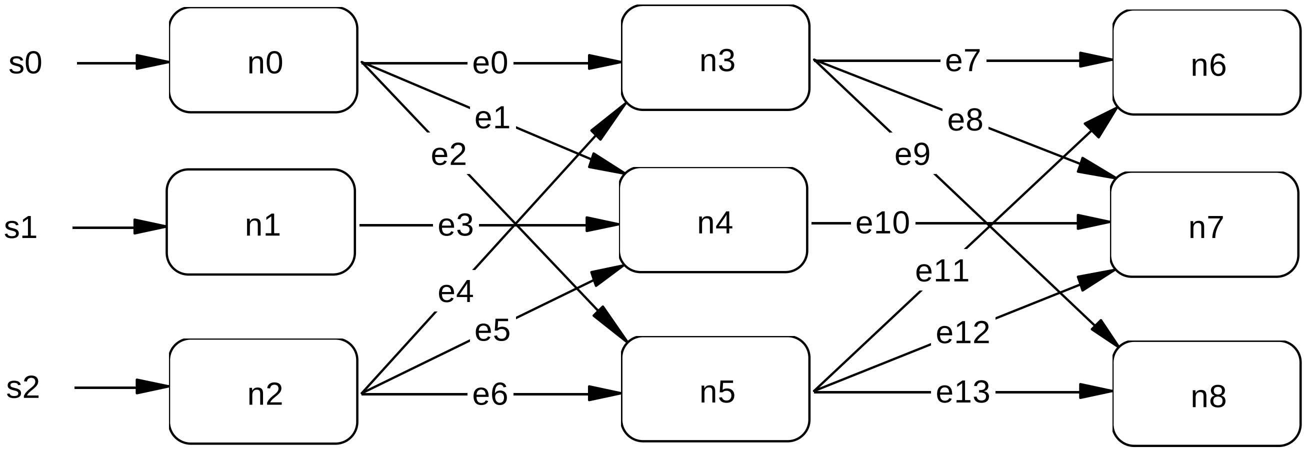
MTA F/E Implementation

- What happens if A is not in the required state when the `load_fe` or `store_ef` arrives?
  - Cray MTA f/e behavior for `load_fe` with A empty.



  - Eventually a timeout occurs, the thread traps to a software handler; the thread state is saved to memory and the thread sleeps until A is marked full.
  - When A becomes full, thread state is reloaded from memory and the `load_fe` is restarted.

Active Graph Representation




```
typedef struct {
  int value;
  int n_edges_in;
  union {
    int *edges_in;
    int streamid;
  } u;
  int n_edges_out;
  int *edges_out;
} Node;

typedef struct {
  int from;
  int to;
  int weight;
  int value;
} Edge;
```

- Dataflow execution of input correlated streams
  - weighted sum at each node
- Nodes, edges, streams are arrays
  - MTA randomly scatters data in physical memory

Scheduling Alternatives

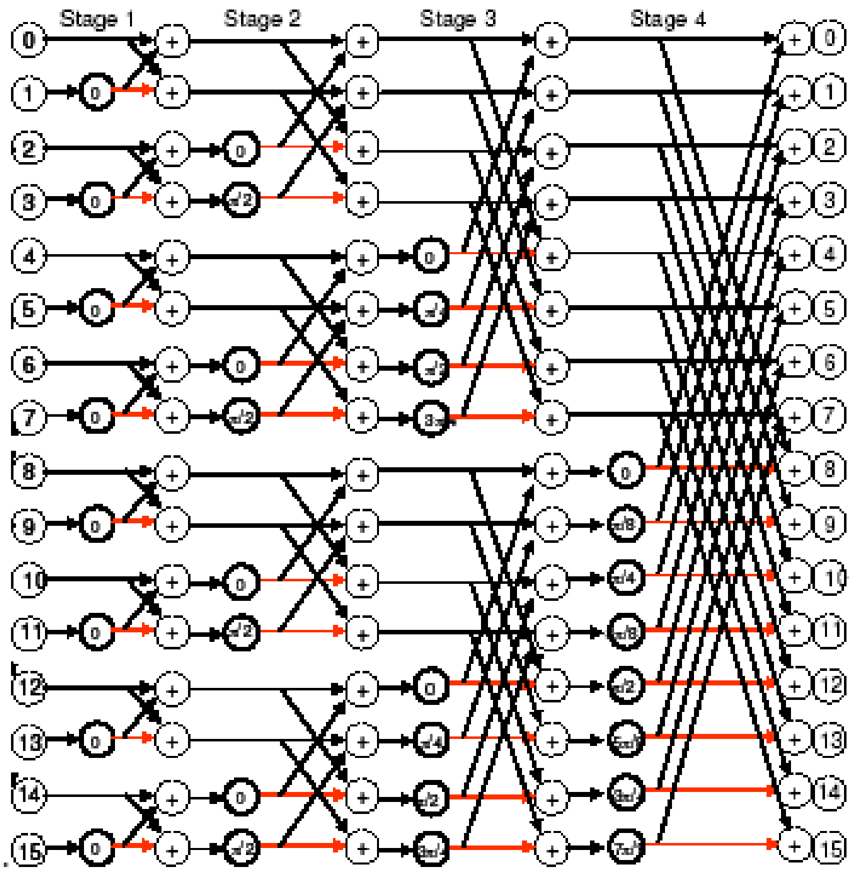
```
for each data set
   for each stage of the graph
      #pragma mta assert parallel
      for each node in that stage
         read()
         compute()
         write()
```

- Synchronous stages
  - stages can be hard to identify in random graphs

```
for each data set
   #pragma mta assert parallel
   for each node in graph
      readfe()
      compute()
      writeef()
```

- Asynchronous using full/empty bits
  - no need to identify stages

Experiment: Parameterized Butterfly Graphs



- Varied
  - Number of nodes
  - Radix
  - Randomly deleted edges
- Run on 10 MTA-2 processor nodes

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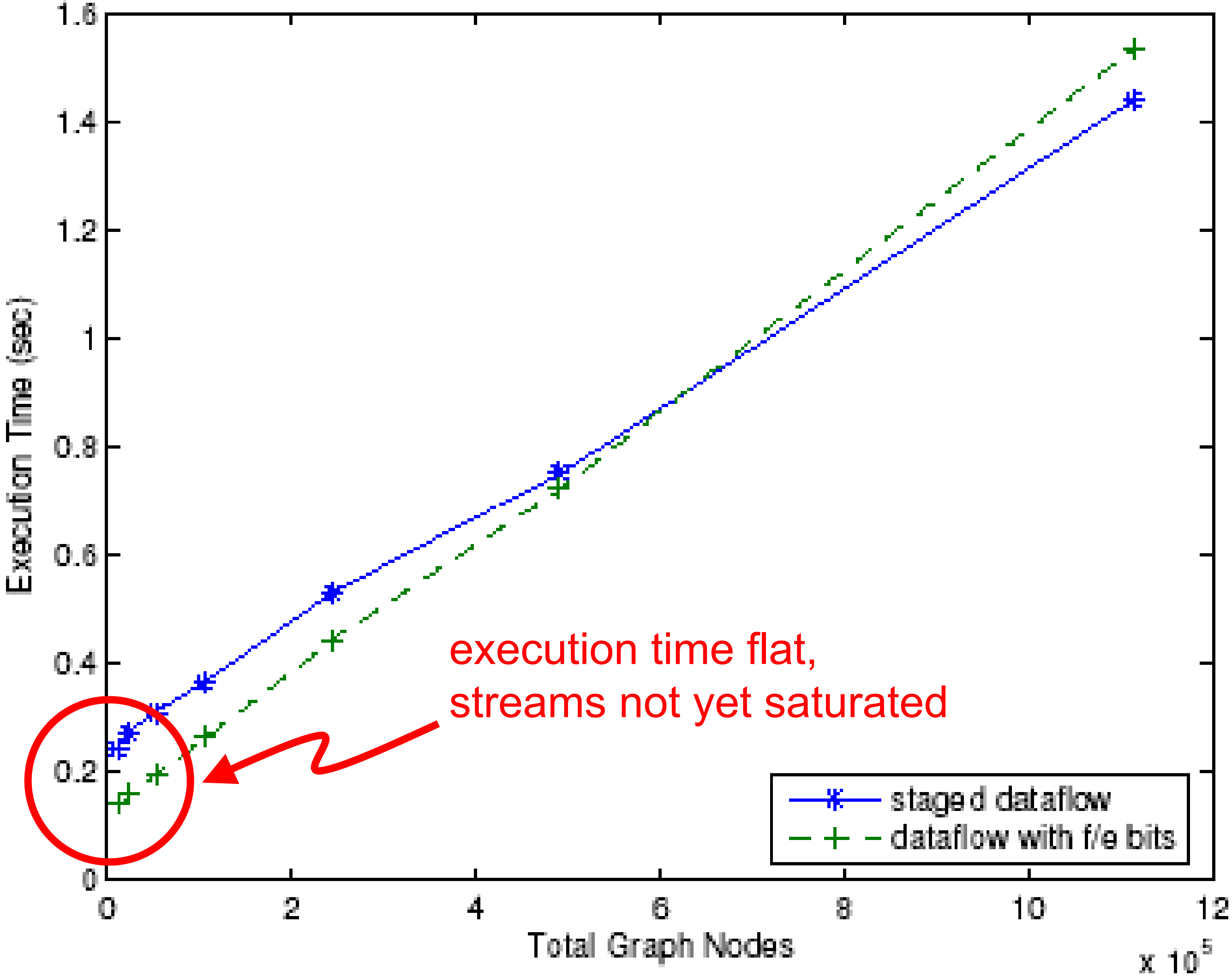
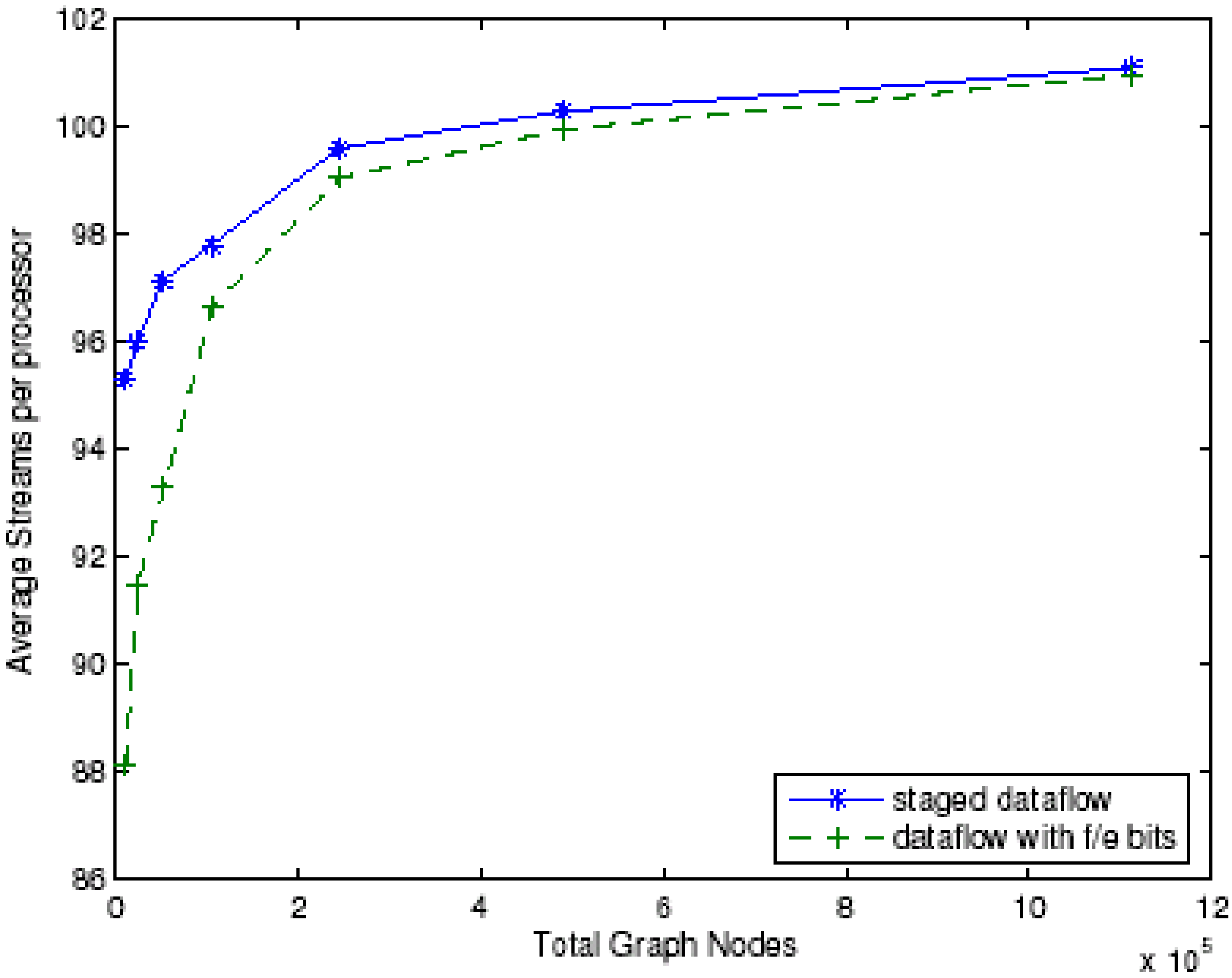
Execution Time

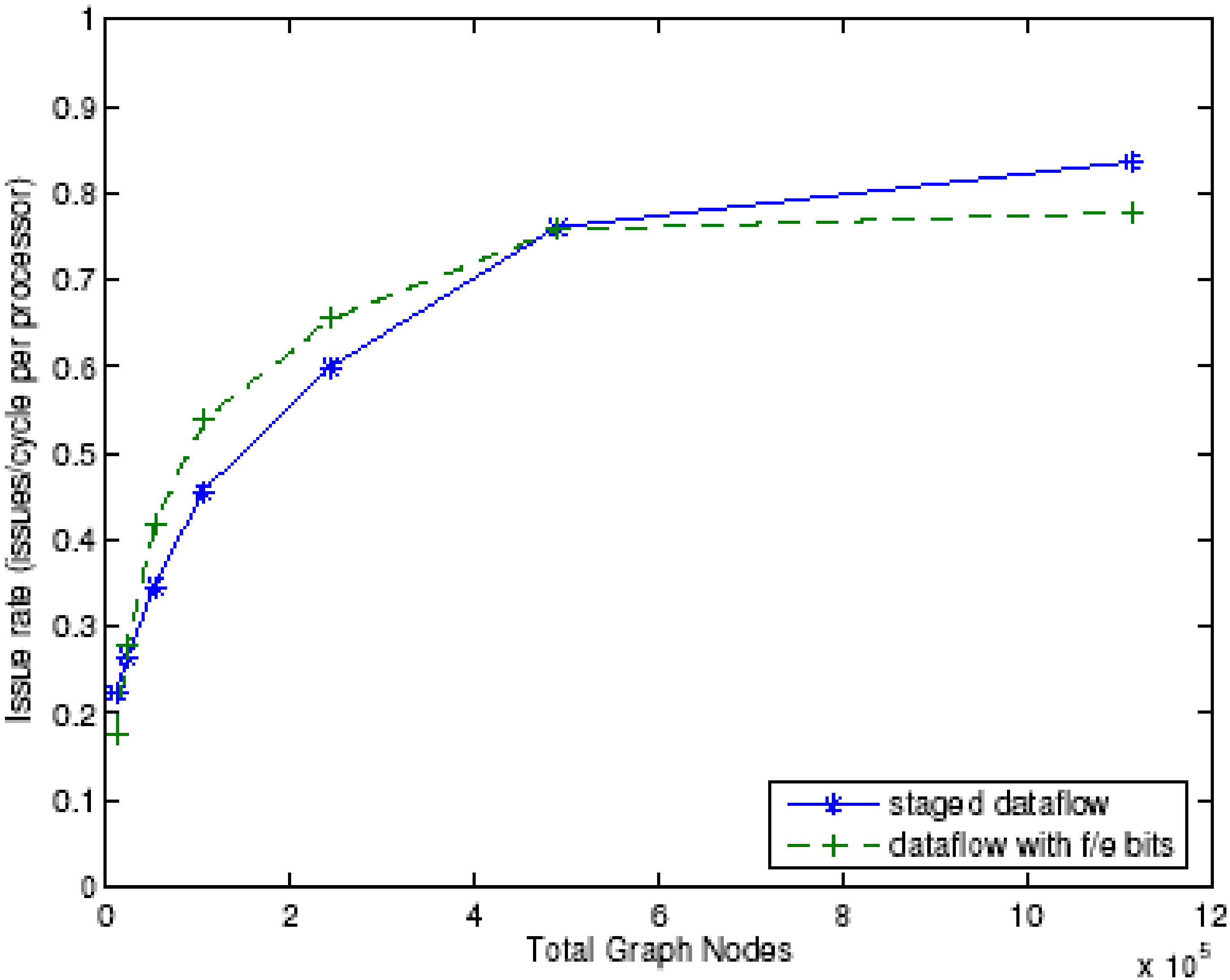


Streams



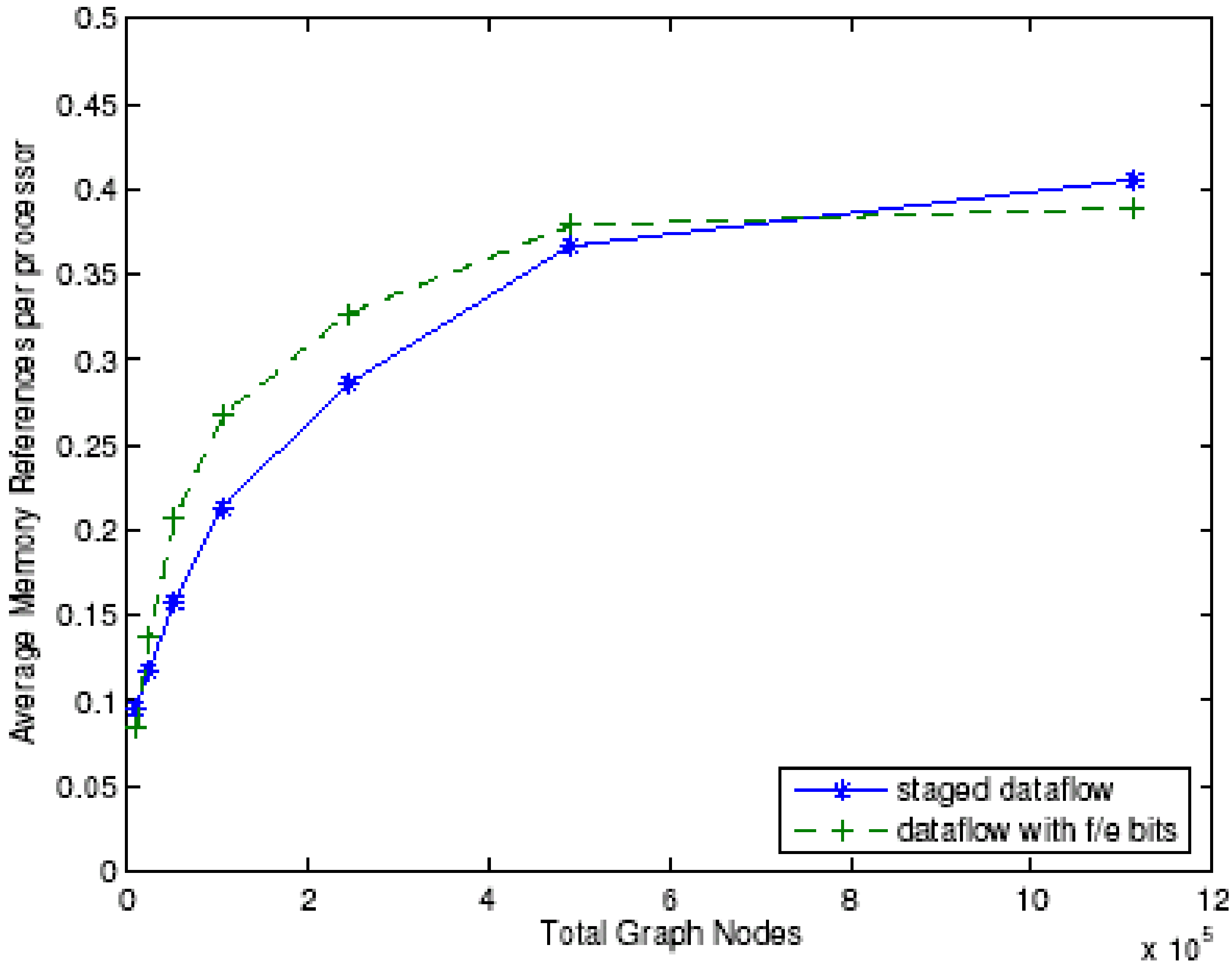
102
100
98
96
94
92
90
88
86
0
2
4
6
8
10
12
Average Streams per processor
Total Graph Nodes
x 10^5
staged dataflow
dataflow with f/e bits

Issue Rate



1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Issue rate (issues/cycle per processor)
0
2
4
6
8
10
12
Total Graph Nodes
x 10^5
staged dataflow
dataflow with f/e bits

Memory References



Trying for More Parallelism

```
#pragma mta assert parallel
for each node in graph
   for each dataset
      readfe()
      compute()
      writeef()
```

- Deadlock after 512 nodes!!!
- Why?
  - Outstripped number of available streams
  - Runtime scheduling becomes an issue

Conclusions and Future Work

- Active graphs are a natural way to formalize systems of interacting agents
  - Easy implementation on MTA
- Very low overhead synchronization using full/empty bits
  - Avoids need for explicit scheduling—to a point
- What's next?
  - More applications, including ZCHAFF SAT solver
  - Investigate PGAS programming models and performance on Eldorado—path to Cascade