HPX

High Performance ParalleX
CCT – Tech Talk Series

Hartmut Kaiser (hkaiser@cct.lsu.edu)
http://stellar.cct.lsu.edu

What's HPX ?

- Exemplar ParalleX runtime system implementation
  - Targeting conventional architectures (Linux based SMPs and clusters)
  - Currently, mainly software only implementation
  - Emphasis on
    - Functionality: finding proper architecture and API's
    - Performance: finding hotspots, contention points, reduce overheads, hide latencies
    - API: finding the minimal but complete set of required functions
    - Driven by real applications (AMR, Contact, Graphs, CFD)
- Should allow retargeting to different platforms
  - Stable basis for long term migration path of applications
  - Highly modular, allows to incorporate different policy implementations
  - First experiments with custom hardware components
- Implemented in C++
  - Utilize compiler for highly optimized implementation
  - Utilize language for best possible user experience/simplest API

Technology Demands new Response

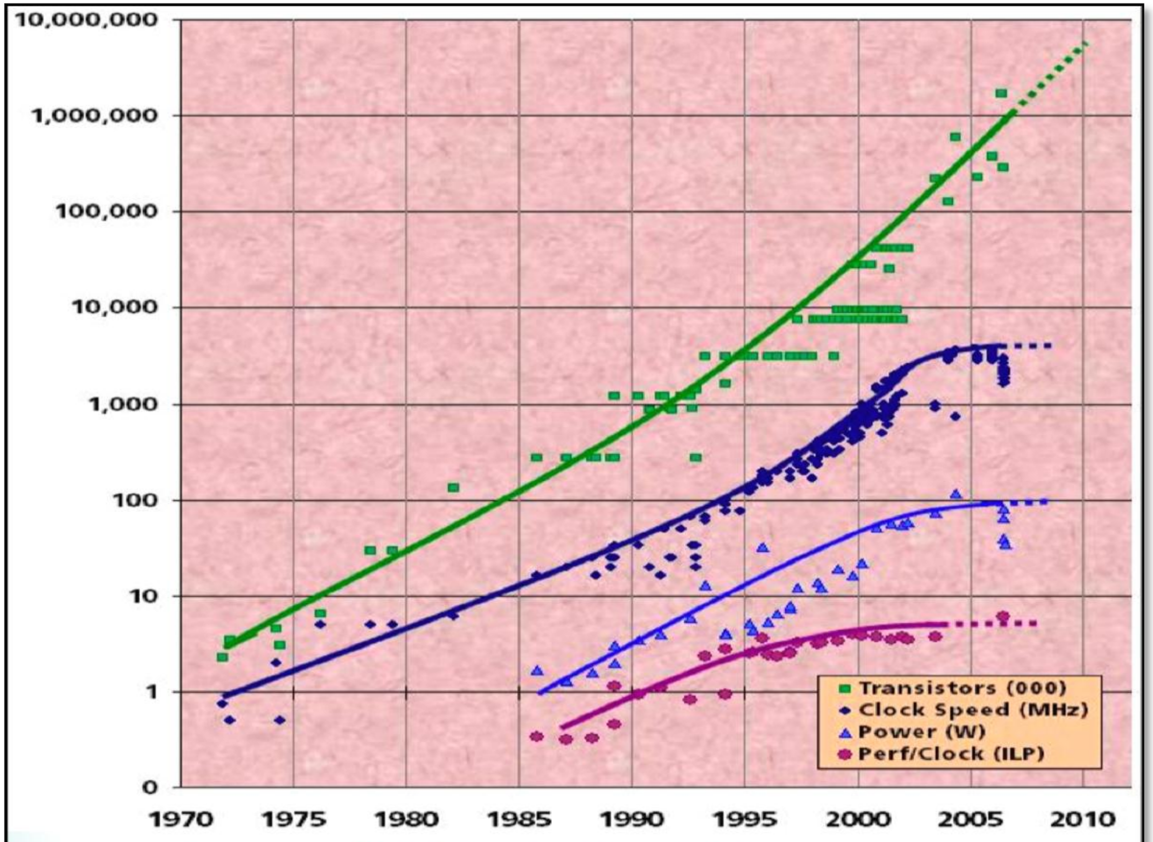

Figure courtesy of Kunle Olukotun, Lance Hammond, Herb Sutter, and Burton Smith

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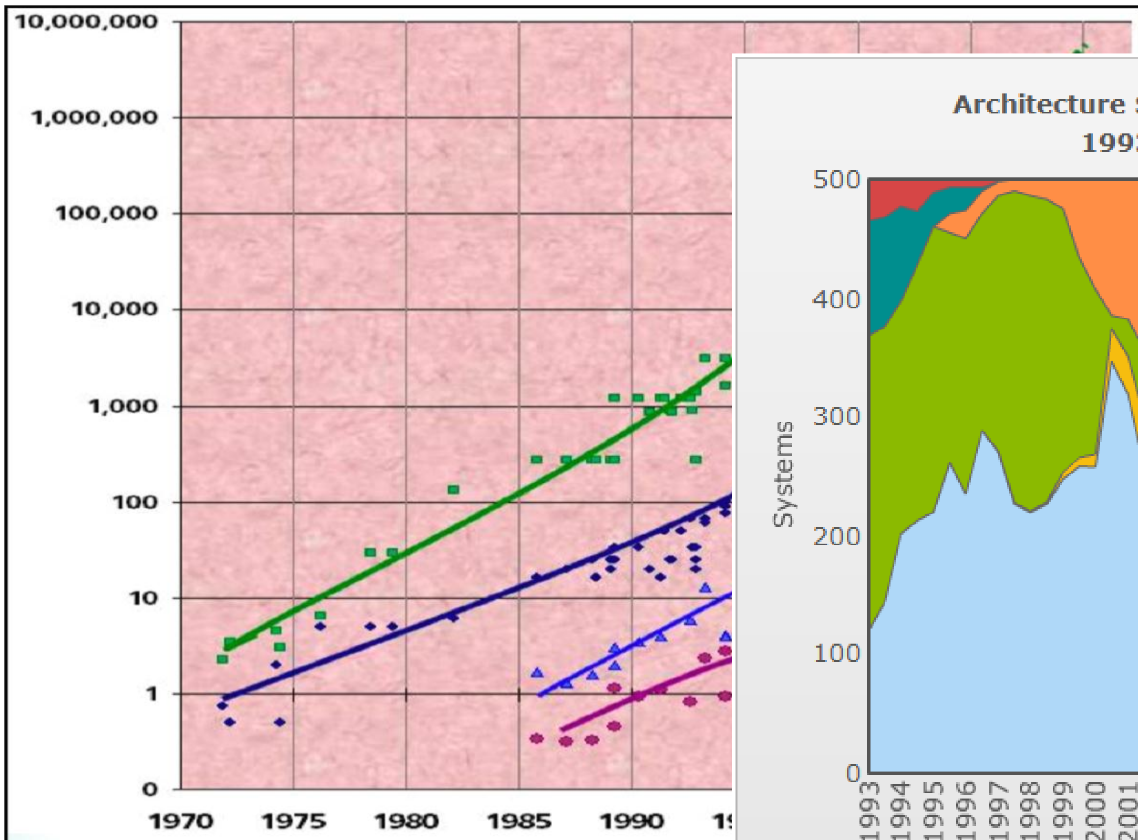

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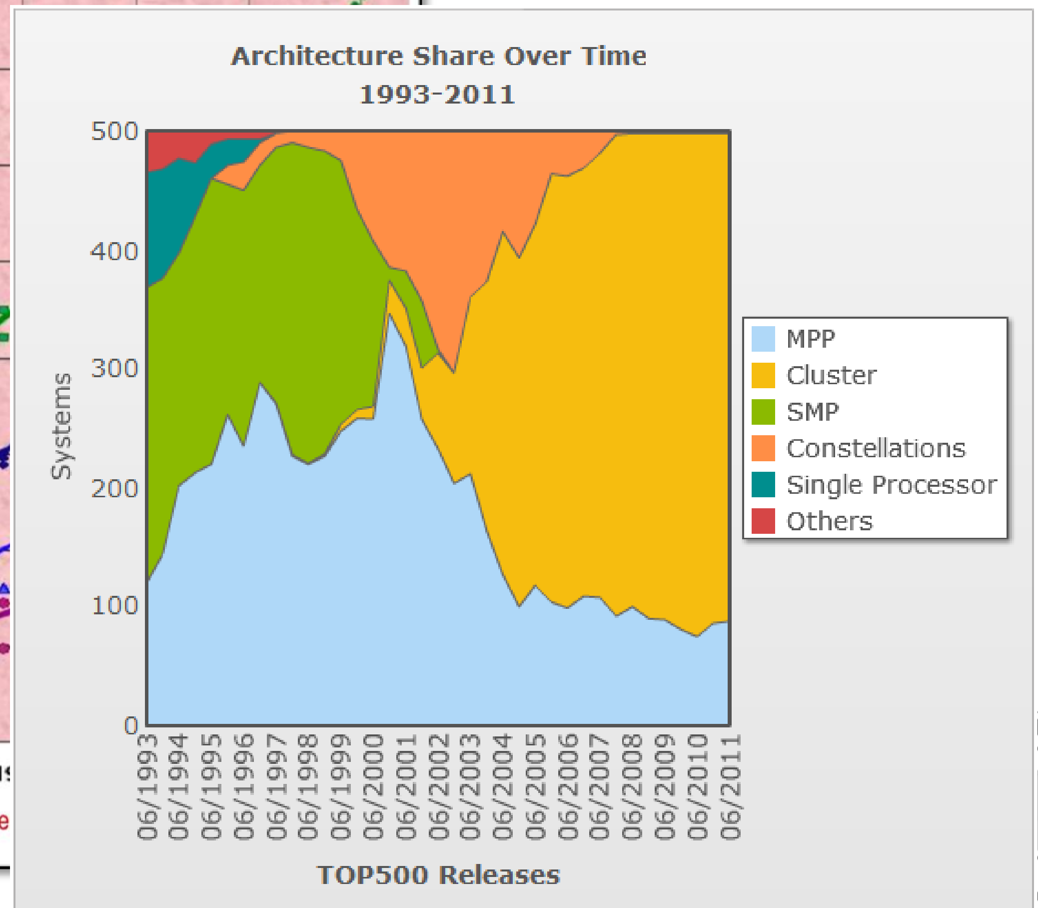

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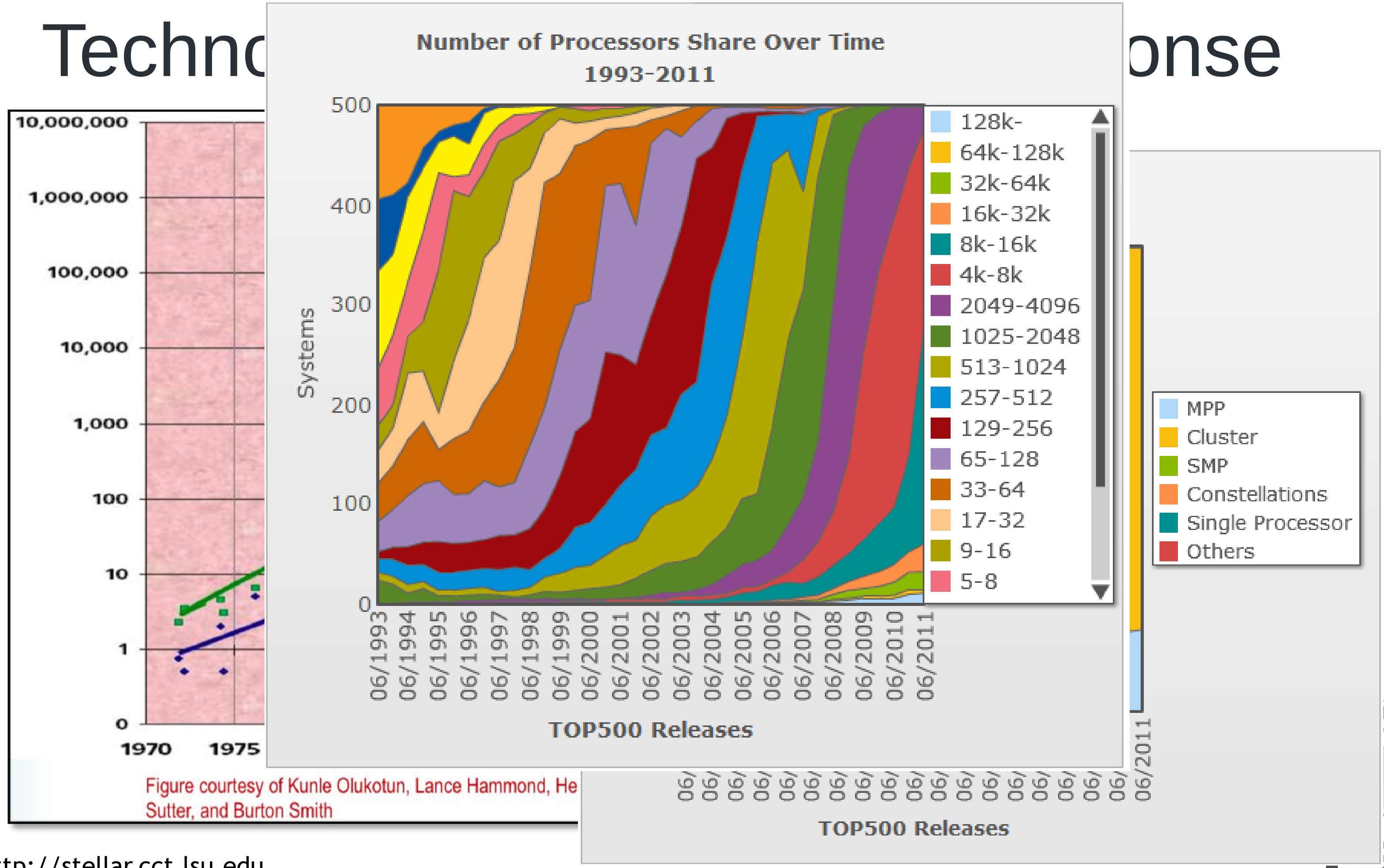

Figure courtesy of Kunle Olukotun, Lance Hammond, He... Sutter, and Burton Smith

Amdahl's Law (Strong Scaling)

$$S = \frac{1}{(1-P) + \frac{P}{N}}$$

- S: Speedup
- P: Proportion of parallel code
- N: Number of processors

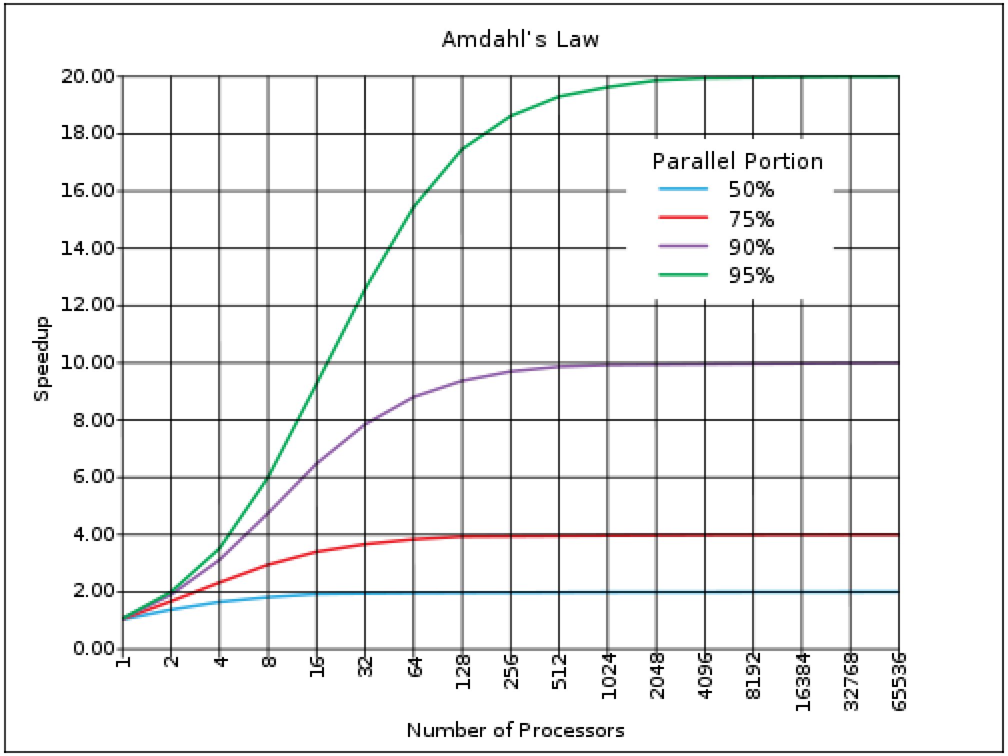

Figure courtesy of Wikipedia (http://en.wikipedia.org/wiki/Amdahl's_law)

Gustafson's Law (Weak Scaling)

$$S = N - P(N - 1)$$

- *S*: Speedup
- *P*: Proportion of parallel code
- *N*: Number of processors

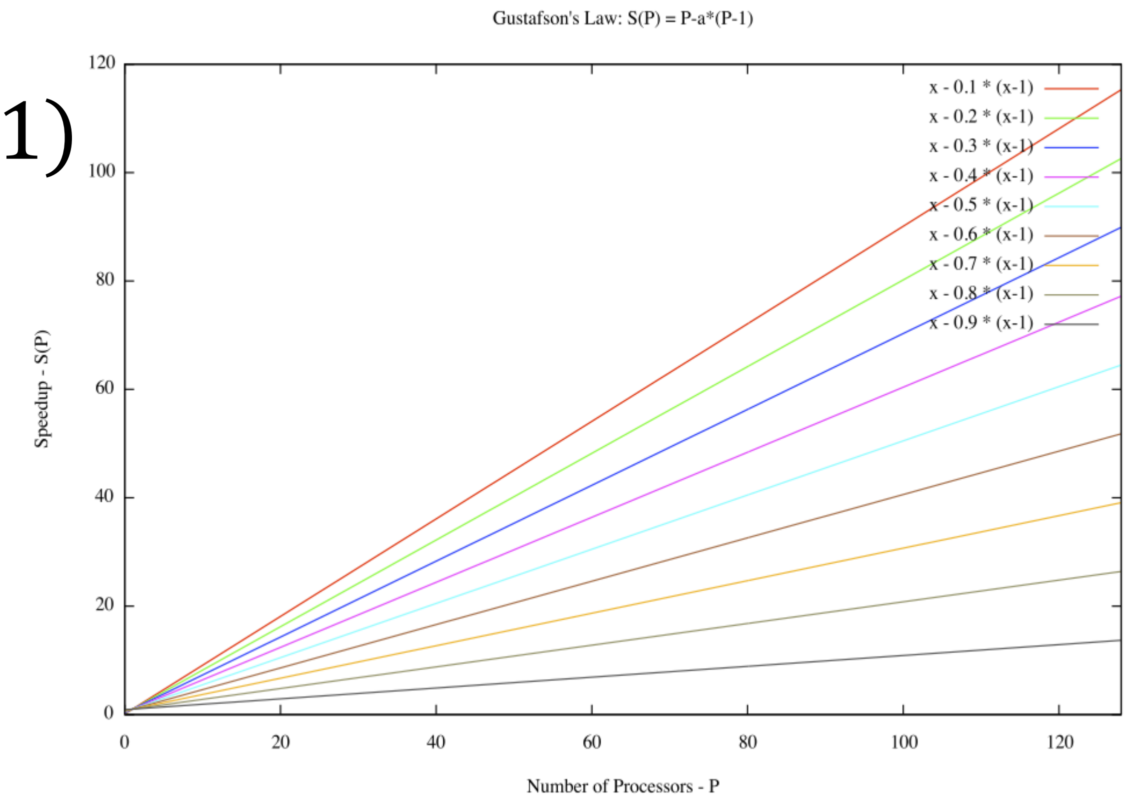

Figure courtesy of Wikipedia (http://en.wikipedia.org/wiki/Gustafson's_law)

The 4 Horsemen of the Apocalypse: SLOW

- **S**tarvation
  - Insufficient concurrent work to maintain high utilization of resources
- **L**atencies
  - Time-distance delay of remote resource access and services
- **O**verheads
  - Work for management of parallel actions and resources on critical path which are not necessary in sequential variant
- **W**aiting for Contention resolution
  - Delays due to lack of availability of oversubscribed shared resource

courtesy of www.albrecht-durer.org

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Impose upper bound on both, weak and strong scaling


courtesy of www.albrecht-durer.org

Main HPX Runtime System Tasks

- Manage parallel execution for the application — Starvation
  - Exposing parallelism, runtime adaptive management of parallelism and resources
  - Synchronizing parallel tasks
  - Thread (task) scheduling, load balancing
- Mitigate latencies for the application — Latency
  - Latency hiding through overlap of computation and communication
  - Latency avoidance through locality management
- Reduce overhead for the application — Overhead
  - Synchronization, scheduling, load balancing, communication, context switching, memory management, address translation
- Resolve contention for the application — Contention
  - Adaptive routing, resource scheduling, load balancing
  - Localized request buffering for logical resources

What's ParalleX ?

- Active global address space (AGAS) instead of PGAS
- Message driven instead of message passing
- Lightweight control objects instead of global barriers
- Latency hiding instead of latency avoidance
- Adaptive locality control instead of static data distribution
- Moving work to data instead of moving data to work
- Fine grained parallelism of lightweight threads instead of Communicating Sequential Processes (CSP/MPI)

HPX Runtime System Design

- Current version of HPX provides the following infrastructure on conventional systems as defined by the ParalleX execution model
  - Active Global Address Space (AGAS)
  - ParalleX Threads and ParalleX Thread Management
  - Parcel Transport and Parcel Management
  - Local Control Objects (LCOs)
  - ParalleX Processes
    - Namespace and policies management, locality control
  - Monitoring subsystem

HPX Runtime System Design

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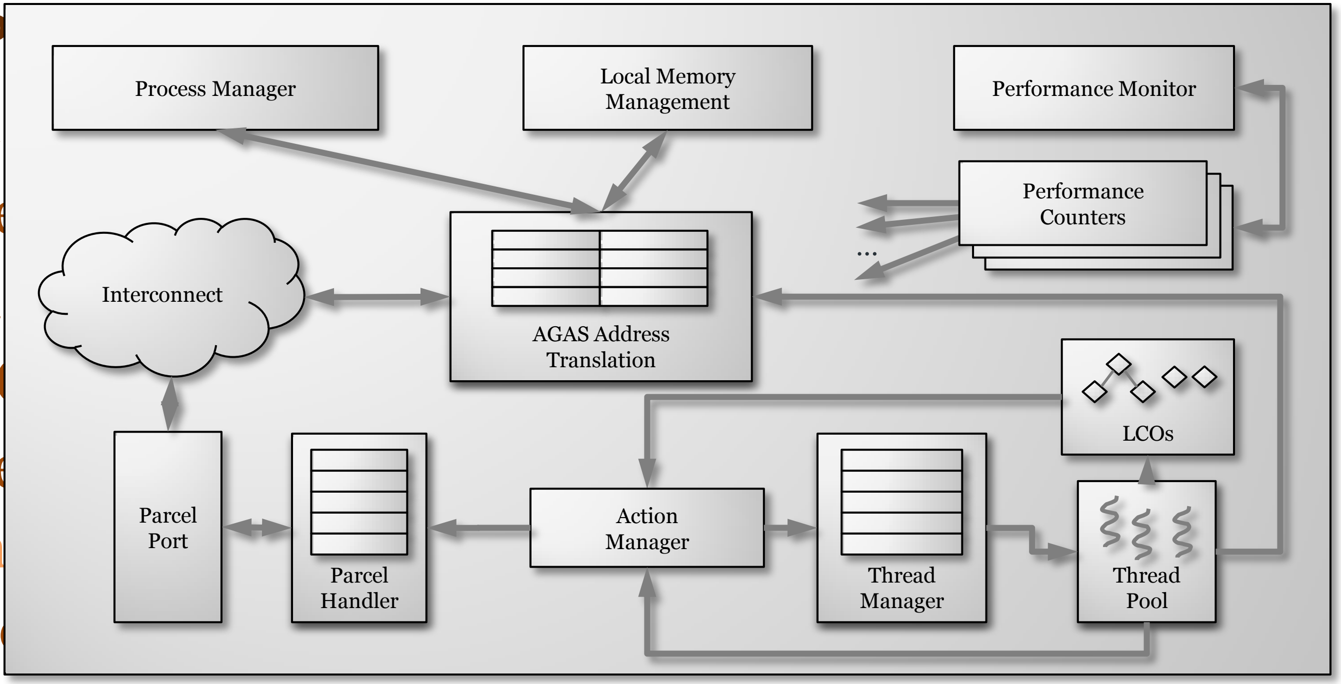

Active Global Address Space

- Global Address Space throughout the system
  - Removes dependency on static data distribution
  - Enables dynamic load balancing of application and system data
- AGAS assigns global names (identifiers, unstructured 128 bit integers) to all entities managed by HPX.
- Unlike PGAS provides a mechanism to resolve global identifiers into corresponding local virtual addresses (LVA)
  - LVAs comprise – Locality ID, Type of Entity being referred to and its local memory address
  - Moving an entity to a different locality updates this mapping
  - Current implementation is based on centralized database storing the mappings which are accessible over the local area network.
  - Local caching policies have been implemented to prevent bottlenecks and minimize the number of required round-trips.
- Current implementation allows autonomous creation of globally unique ids in the locality where the entity is initially located and supports memory pooling of similar objects to minimize overhead
- Implemented garbage collection scheme of HPX objects

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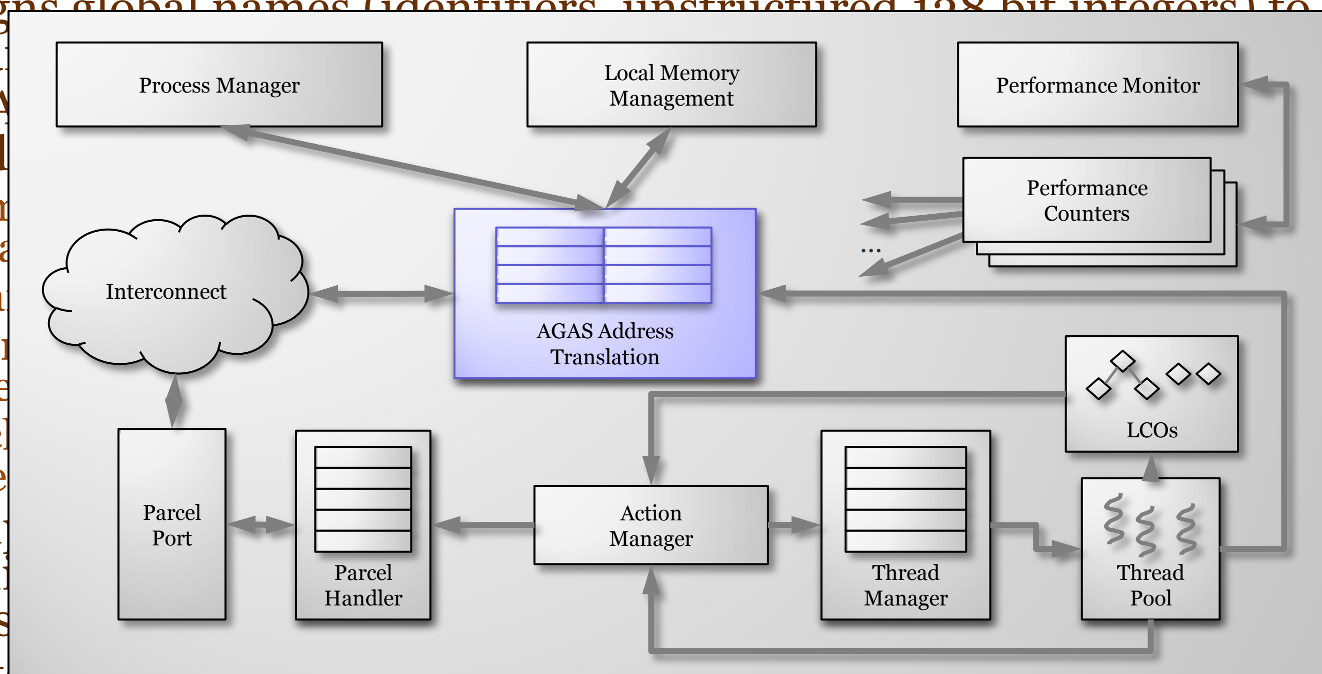
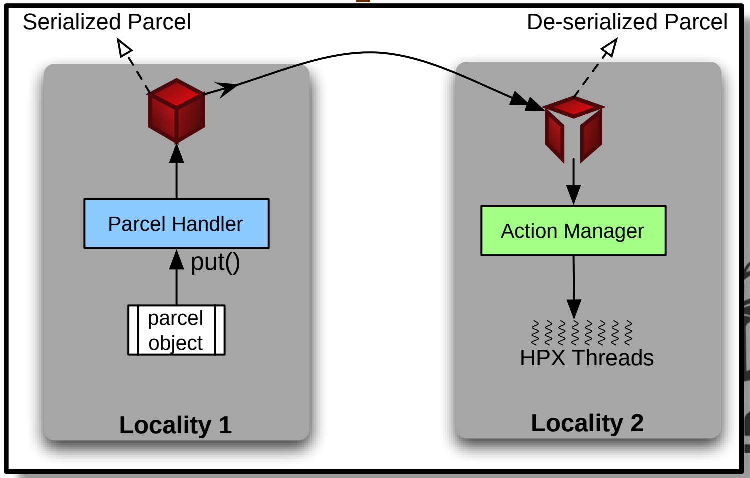


Parcel Management

- Active messages (parcels)
  - Destination address, function to execute, parameters, continuation
- Any inter-locality messaging is based on Parcels
  - In HPX parcels are represented as polymorphic objects
- An HPX entity on creating a parcel object hands it to the parcel handler.
- The parcel handler serializes the parcel where all dependent data is bundled along with the parcel
- At the receiving locality the parcel is de-serialized and causes a HPX thread to be created based on its content



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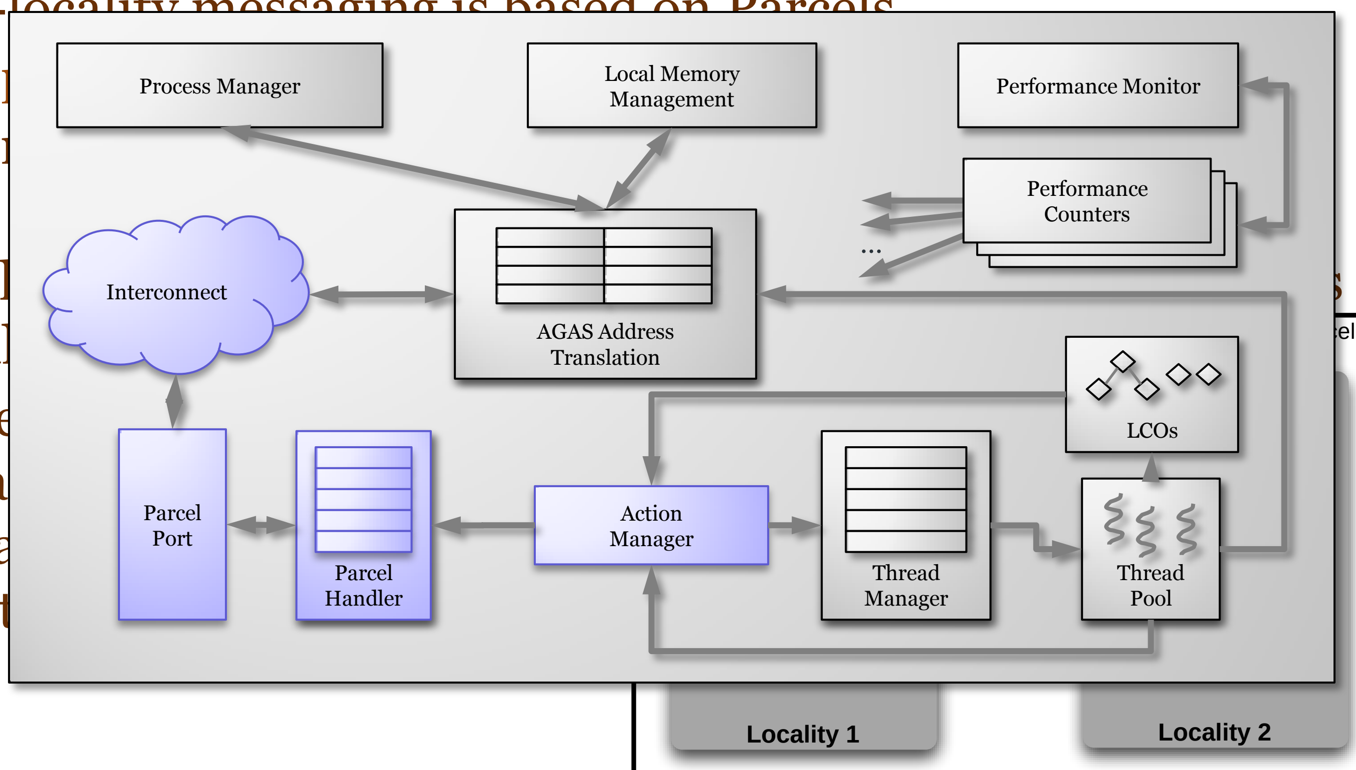

Thread Management

- Thread manager is modular and implements a work-queue based management as specified by the ParalleX execution model
- Threads are cooperatively scheduled at user level without requiring a kernel transition
- Specially designed synchronization primitives such as semaphores, mutexes etc. allow synchronization of PX-threads in the same way as conventional threads
- Thread management currently supports several key modes
  - Global Thread Queue
  - Local Queue (work stealing)
  - Local Priority Queue (work stealing)

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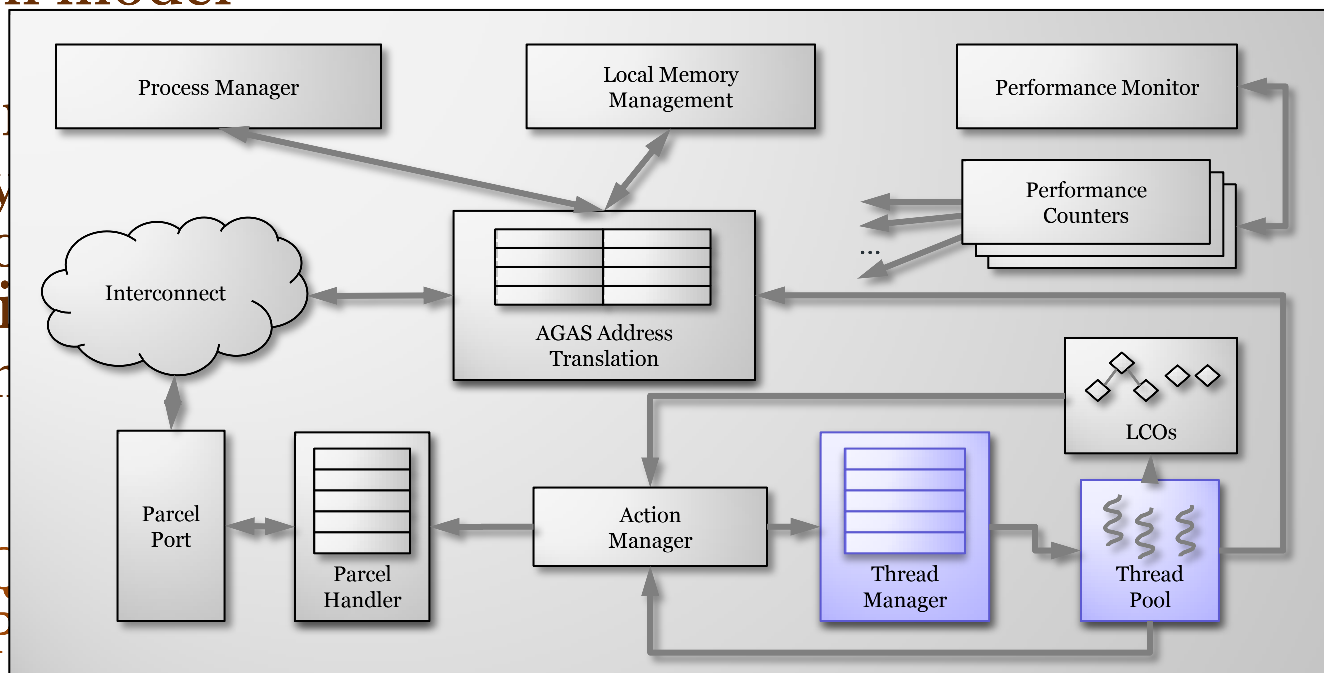
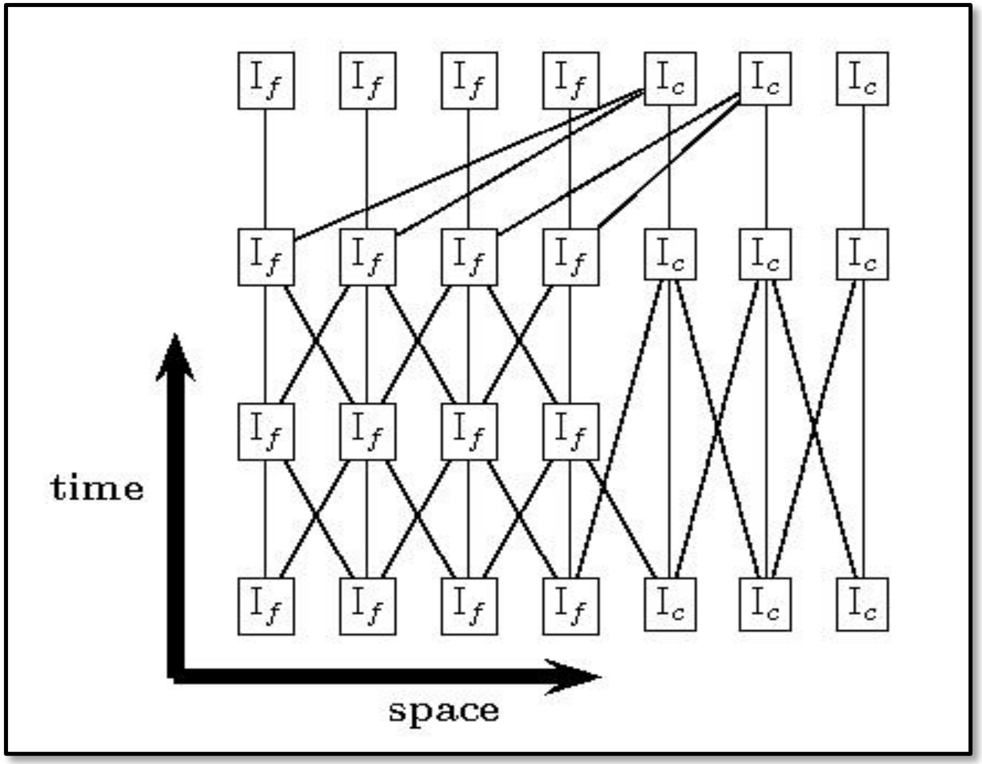


Constraint based Synchronization



- Compute dependencies at task instantiation time
- No global barriers, uses constraint based synchronization
- Computation flows at its own pace
- Message driven
- Symmetry between local and remote task creation/execution
- Possibility to control grain size

LCOs (Local Control Objects)

- LCOs provide a means of controlling parallelization and synchronization of PX-threads
- Enable event-driven thread creation and can support in-place data structure protection and on-the-fly scheduling
- Preferably embedded in the data structures they protect
- Abstraction of a multitude of different functionalities for
  - event driven PX-thread creation,
  - protection of data structures from race conditions
  - automatic on-the-fly scheduling of work
- LCO may create (or reactivate) a PX-thread as a result of ‘being triggered’

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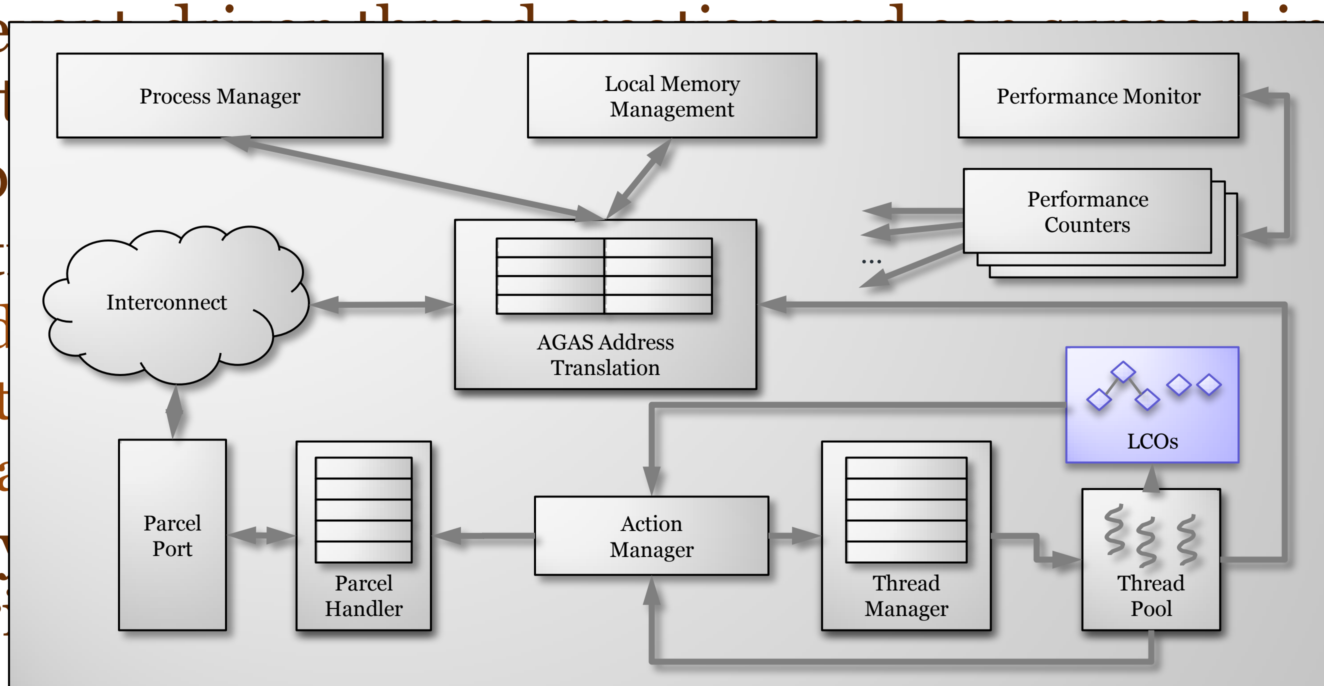
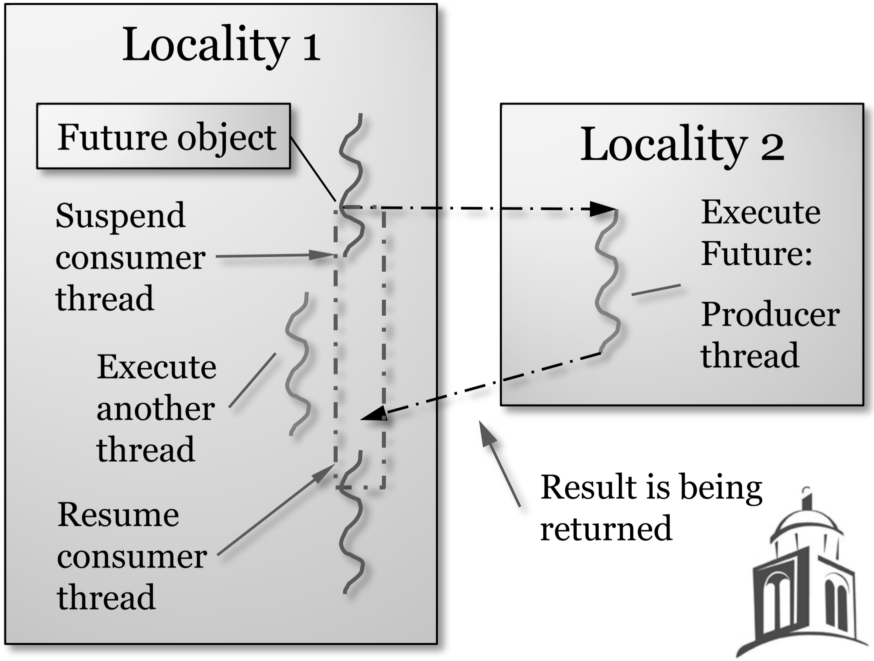


Exemplar LCO: Futures

- In HPX Futures LCO refers to an object that acts as a proxy for the result that is initially not known.
- When a user code invokes a future (using future.get()) the thread can do one of 2 activities
  - If the remote data/arguments are available then the future.get() operation fetches the data and the execution of the thread continues
  - If the remote data is NOT available the thread may continue until it requires the actual value; then the thread suspends allowing other threads to continue execution. The original thread re-activates as soon as the data dependency is resolved



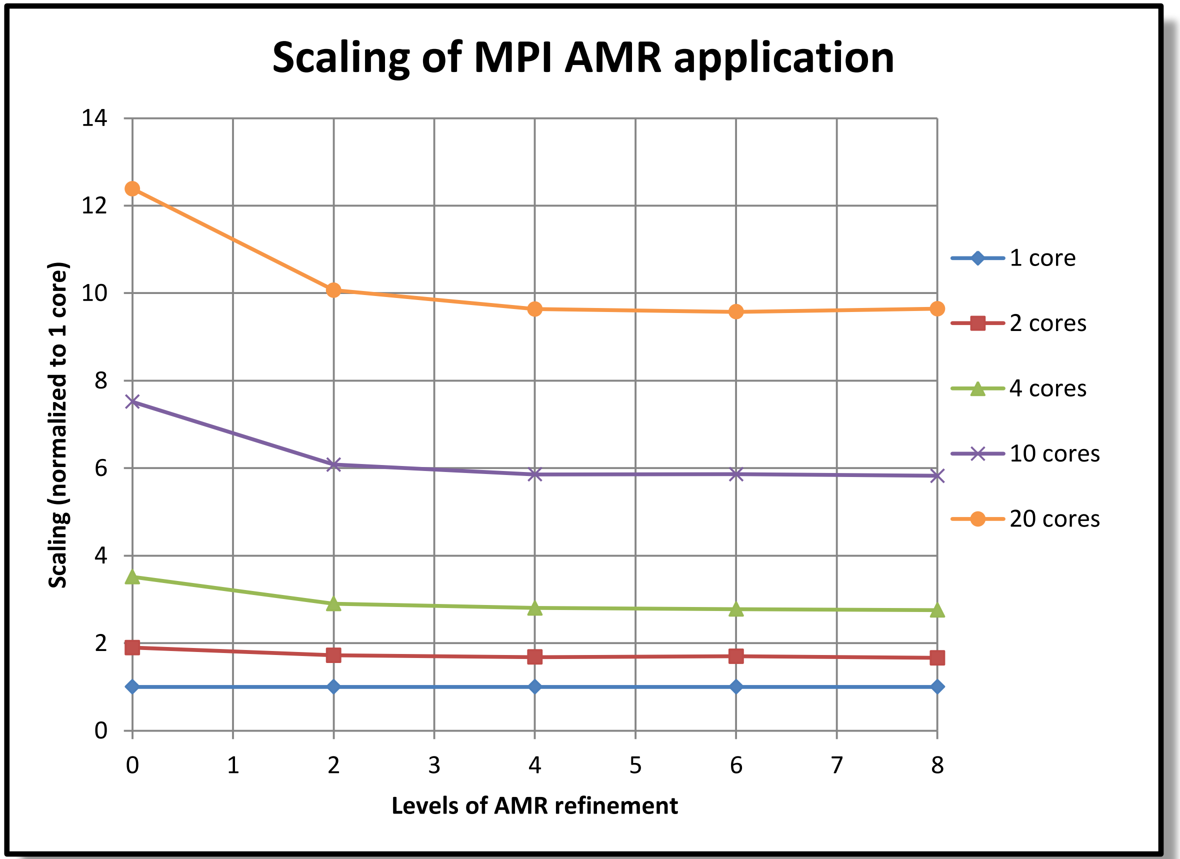
ParalleX Processes

- Management of namespace and locality
  - Centerpiece for truly distributed AGAS
  - We completed the first step in re-implementing AGAS towards being distributed
- Encapsulation of blocks of functionality and possibly distributed data
  - Completed software architecture design for processes
  - Implemented prototypical processes managing read-only distributed data

Recent Results

- First formal release of HPX3 (V0.6), V1.0 scheduled for May
- Re-implemented AGAS on top of Parcel transport layer
  - Better distributed scalability, better asynchrony, latency hiding
- First results implementing ParalleX processes
  - Distributed (read-only) data partitioning of very large data sets
- First (encouraging) results from distributed runs
  - Demonstrated strong scaling similar to SMP
- Consolidated performance counter monitoring framework
  - Allows to measure almost arbitrary system characteristics using unified interface
- Implemented remote application steering
  - Used to demonstrate control of power consumption
- New applications
  - Linear algebra, N-body, chess, contact, graph500

Scaling & performance: AMR using MPI and HPX



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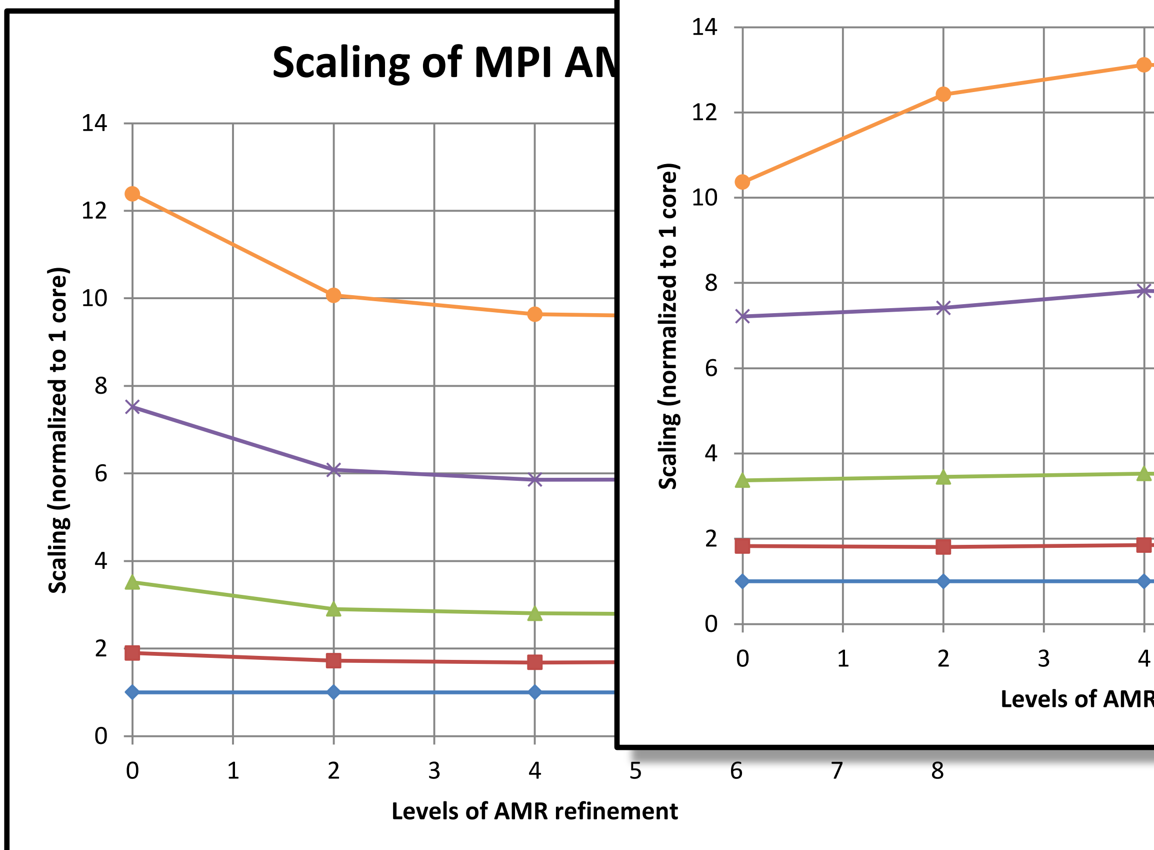

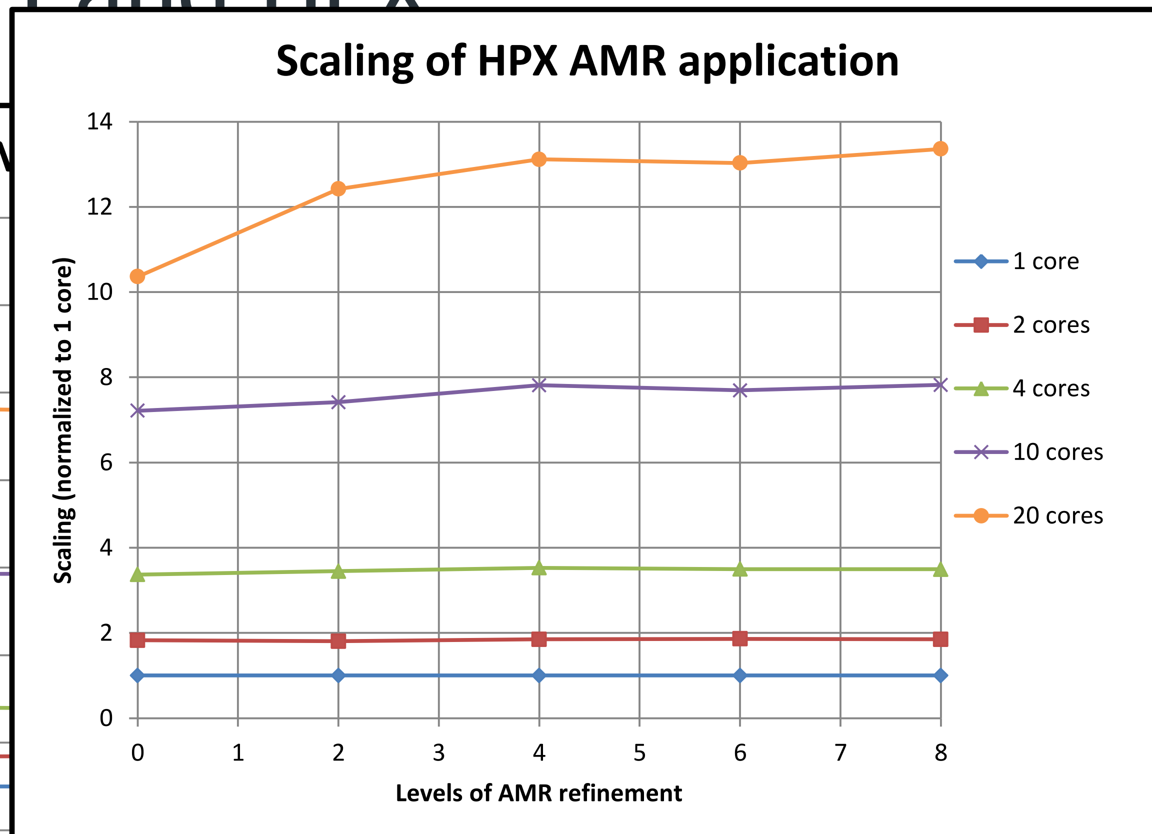

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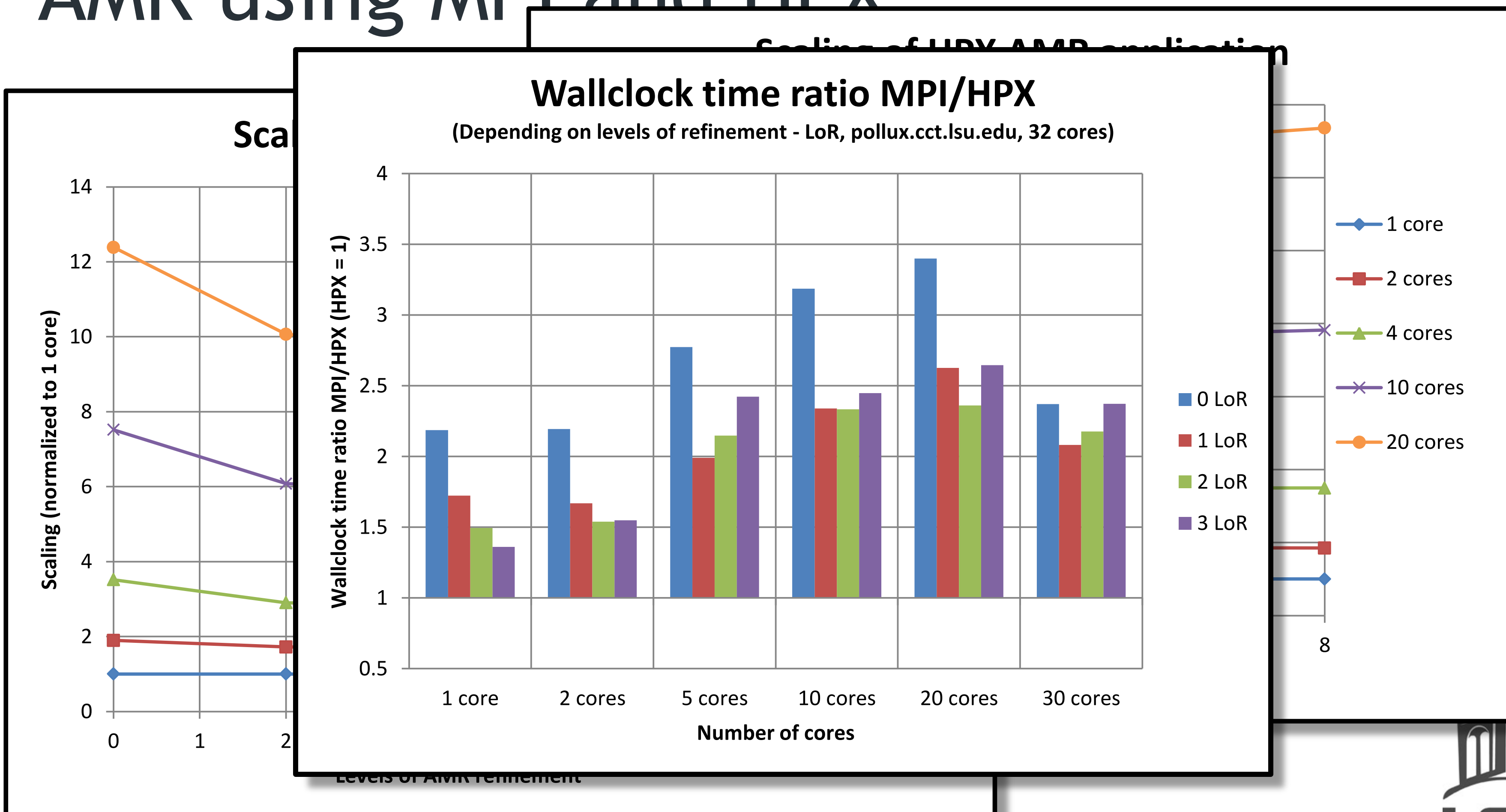
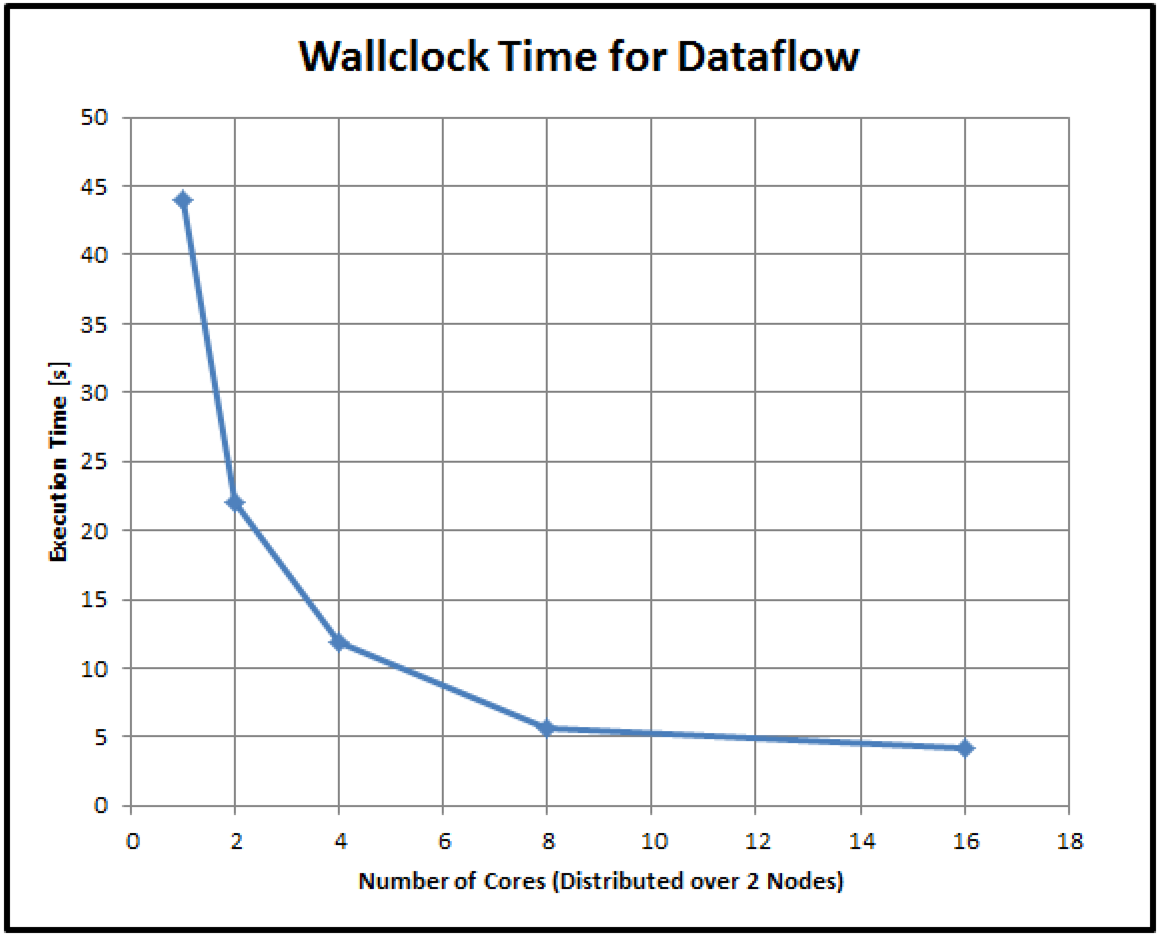


Distributed Strong Scaling



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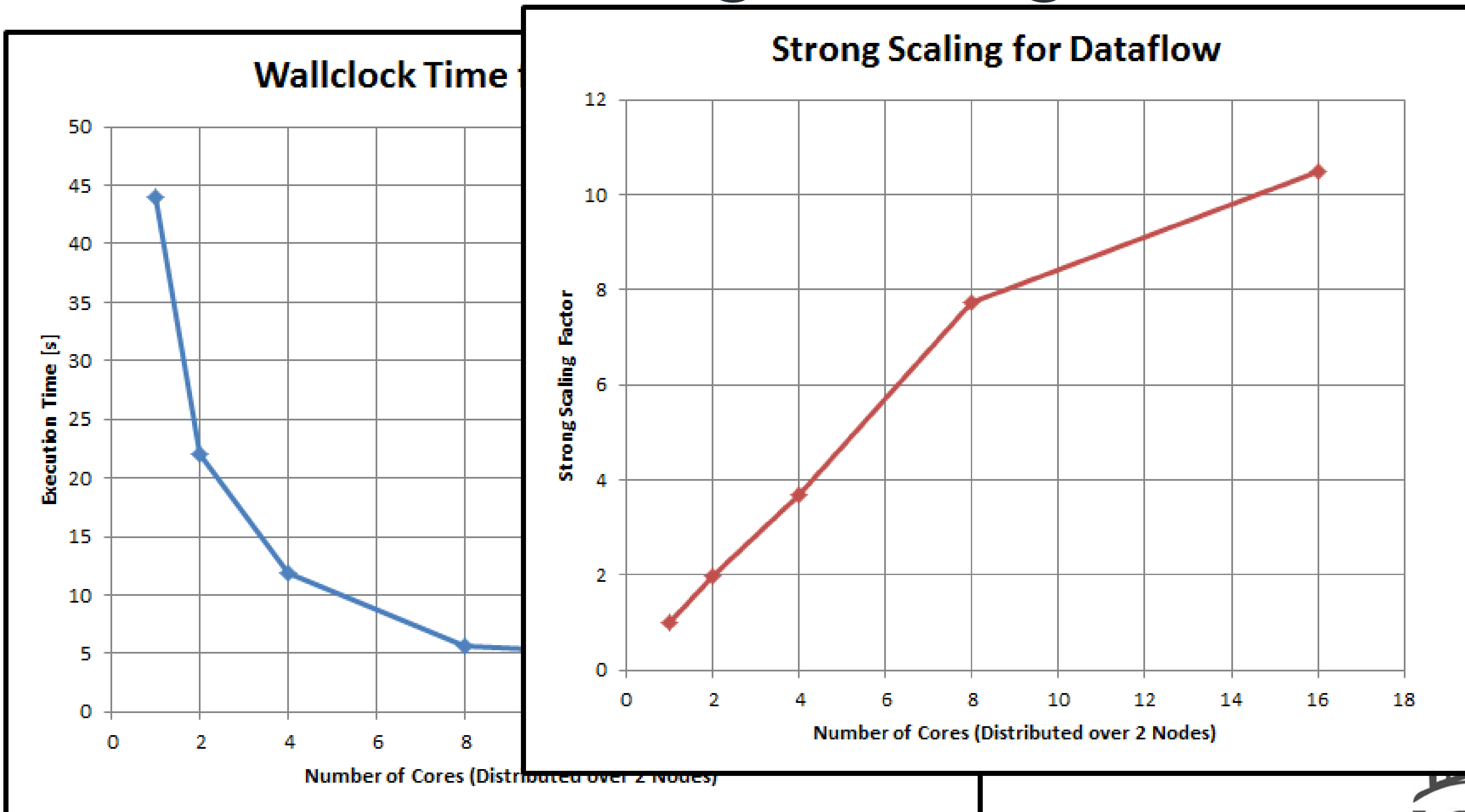
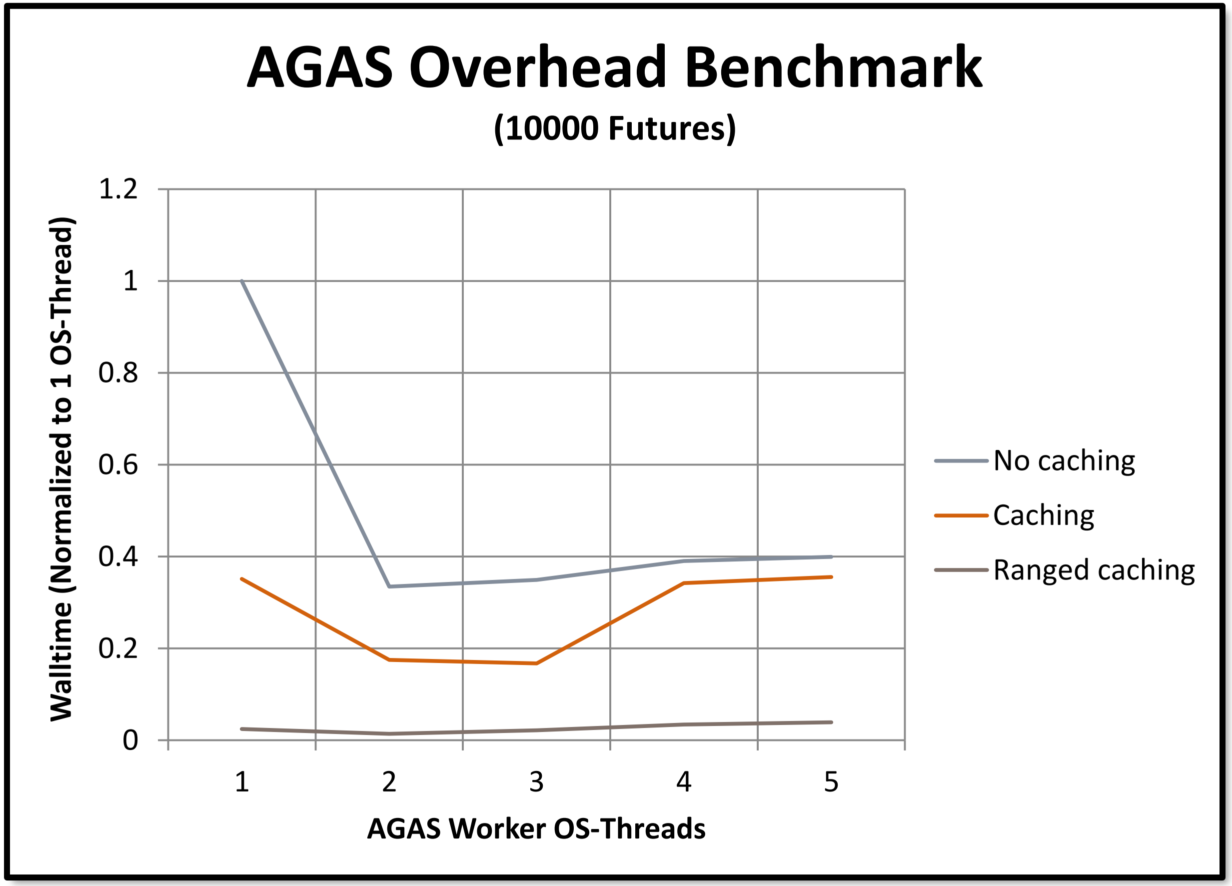
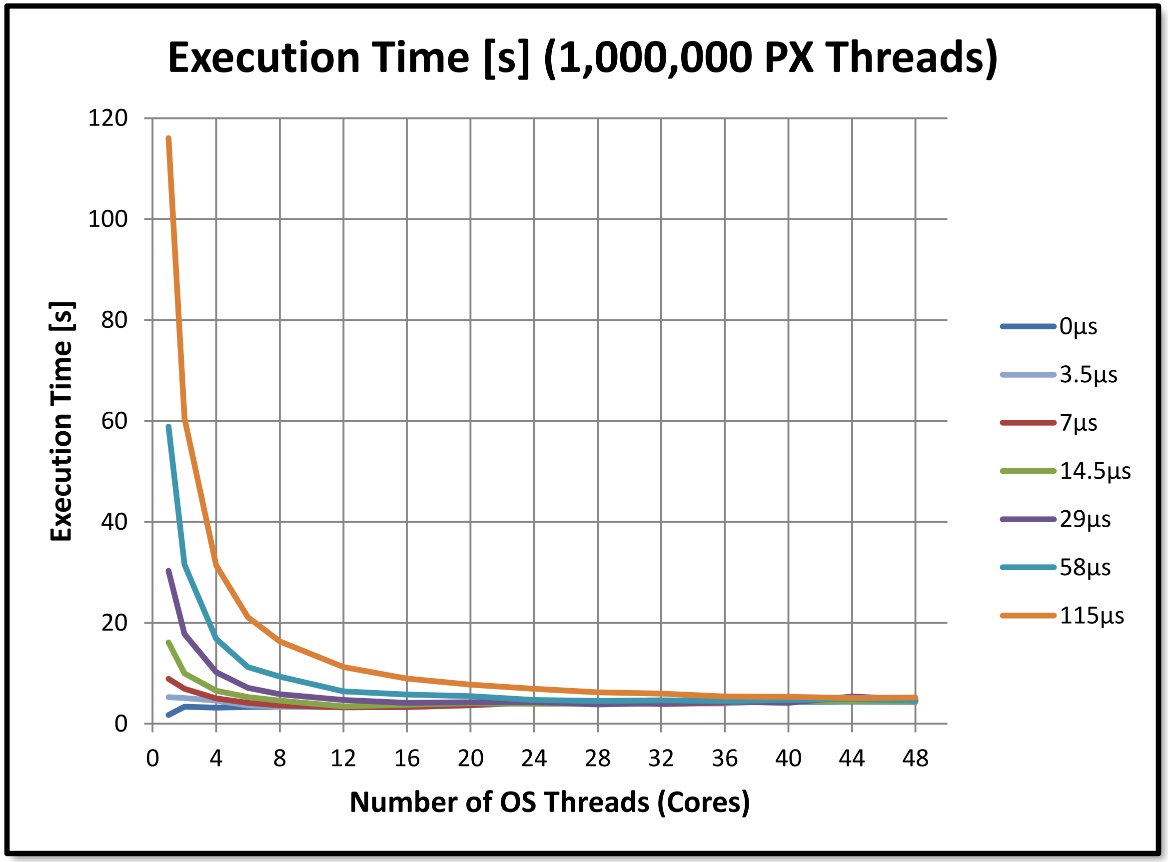


Overheads: AGAS



Overhead: Threads



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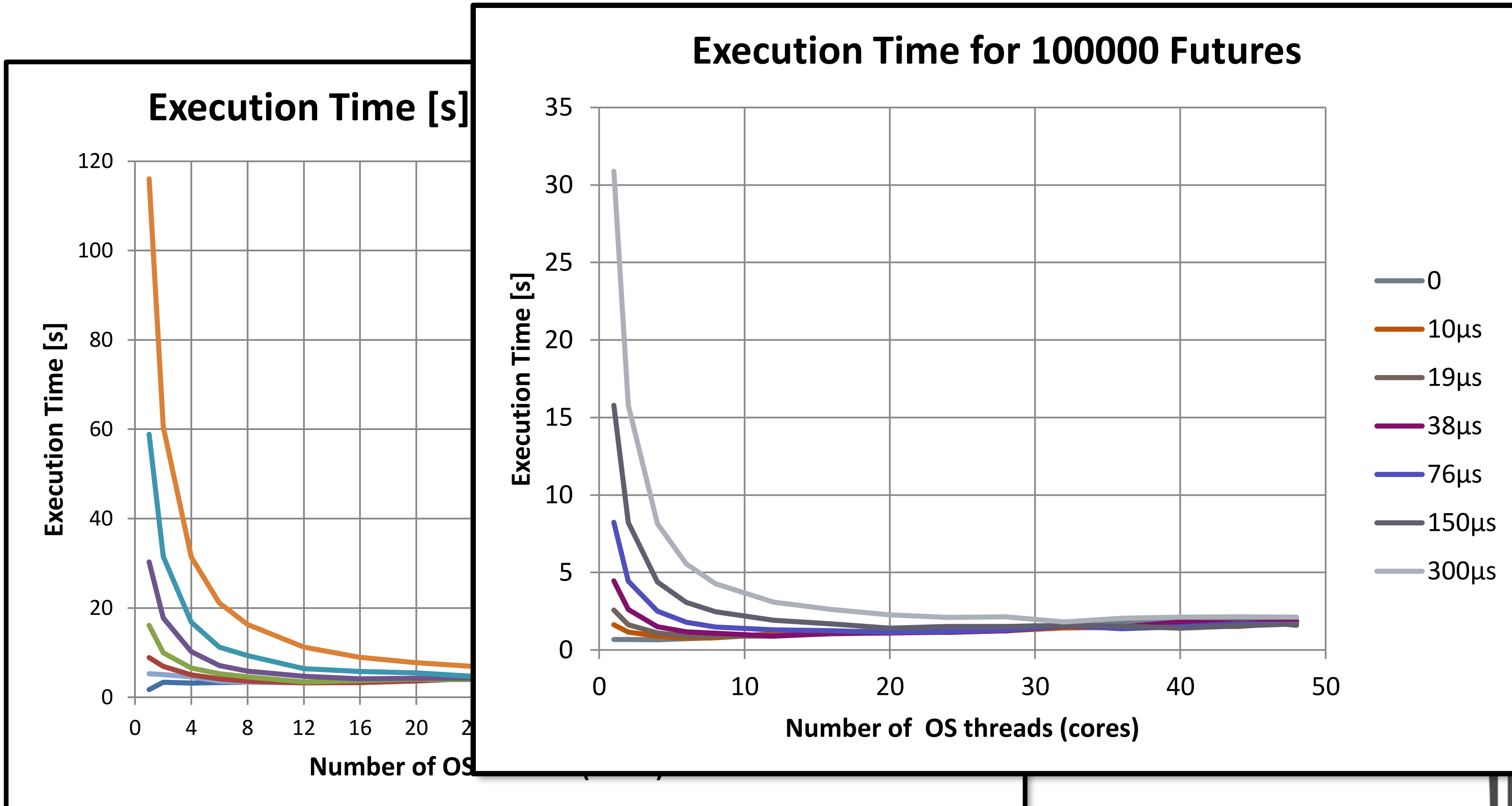
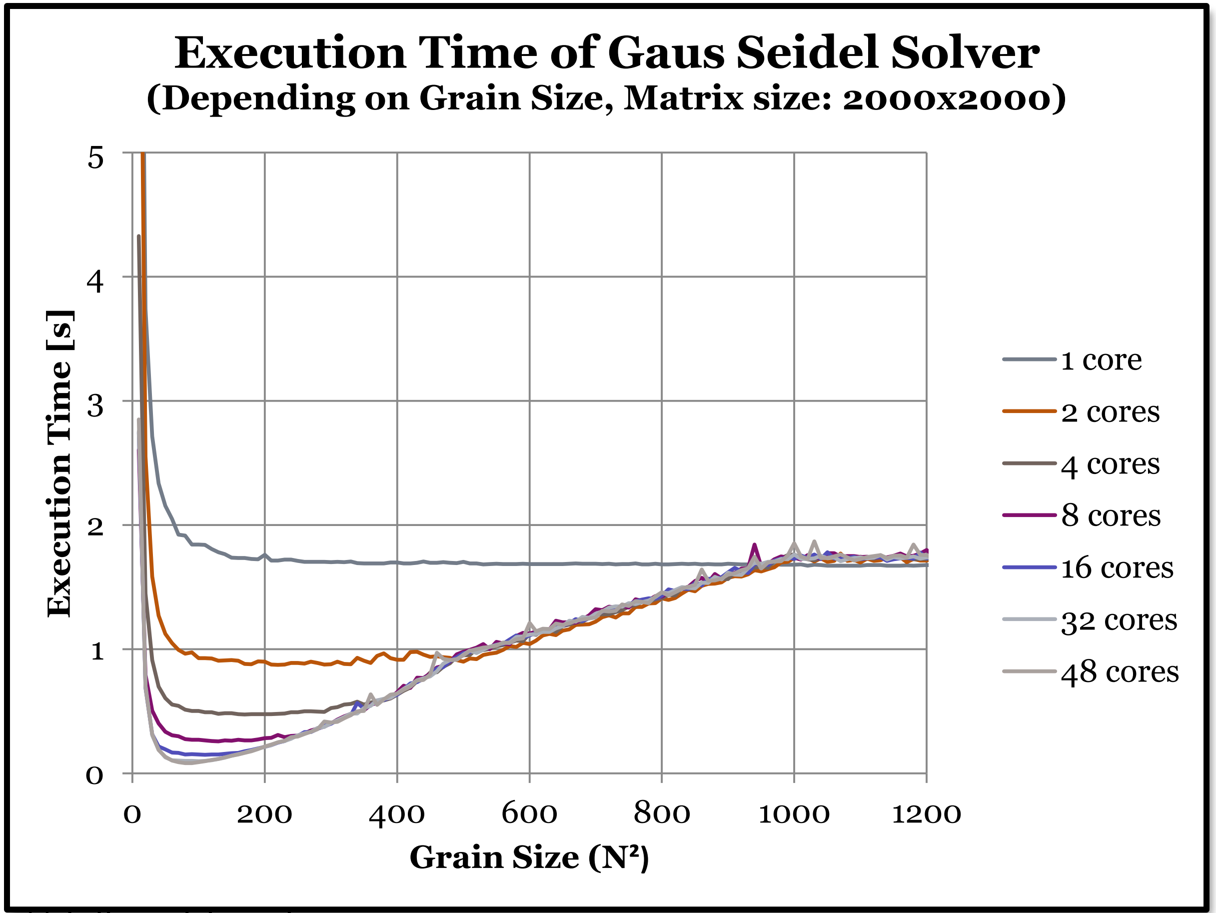


Results from a Gauss-Seidel Solver



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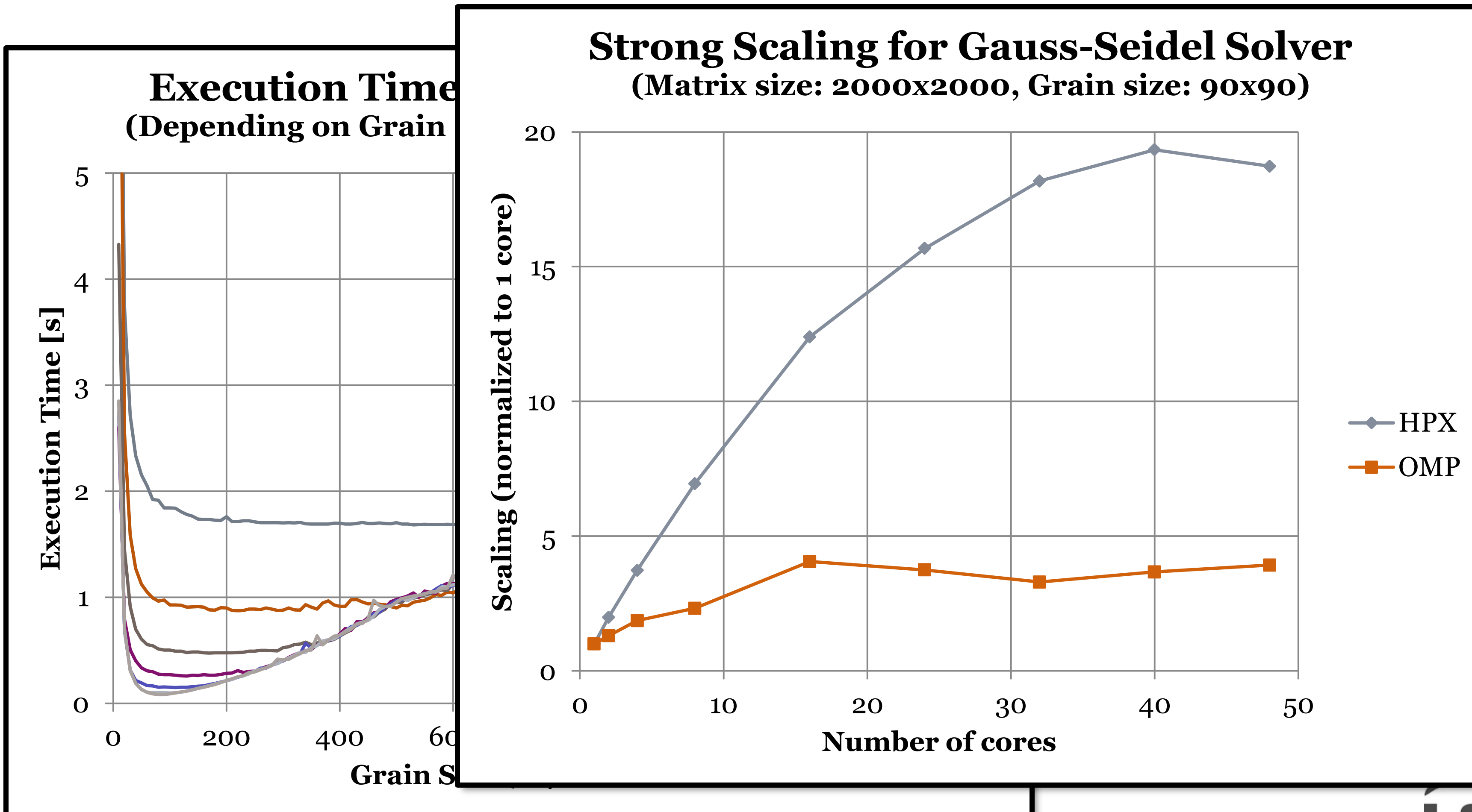
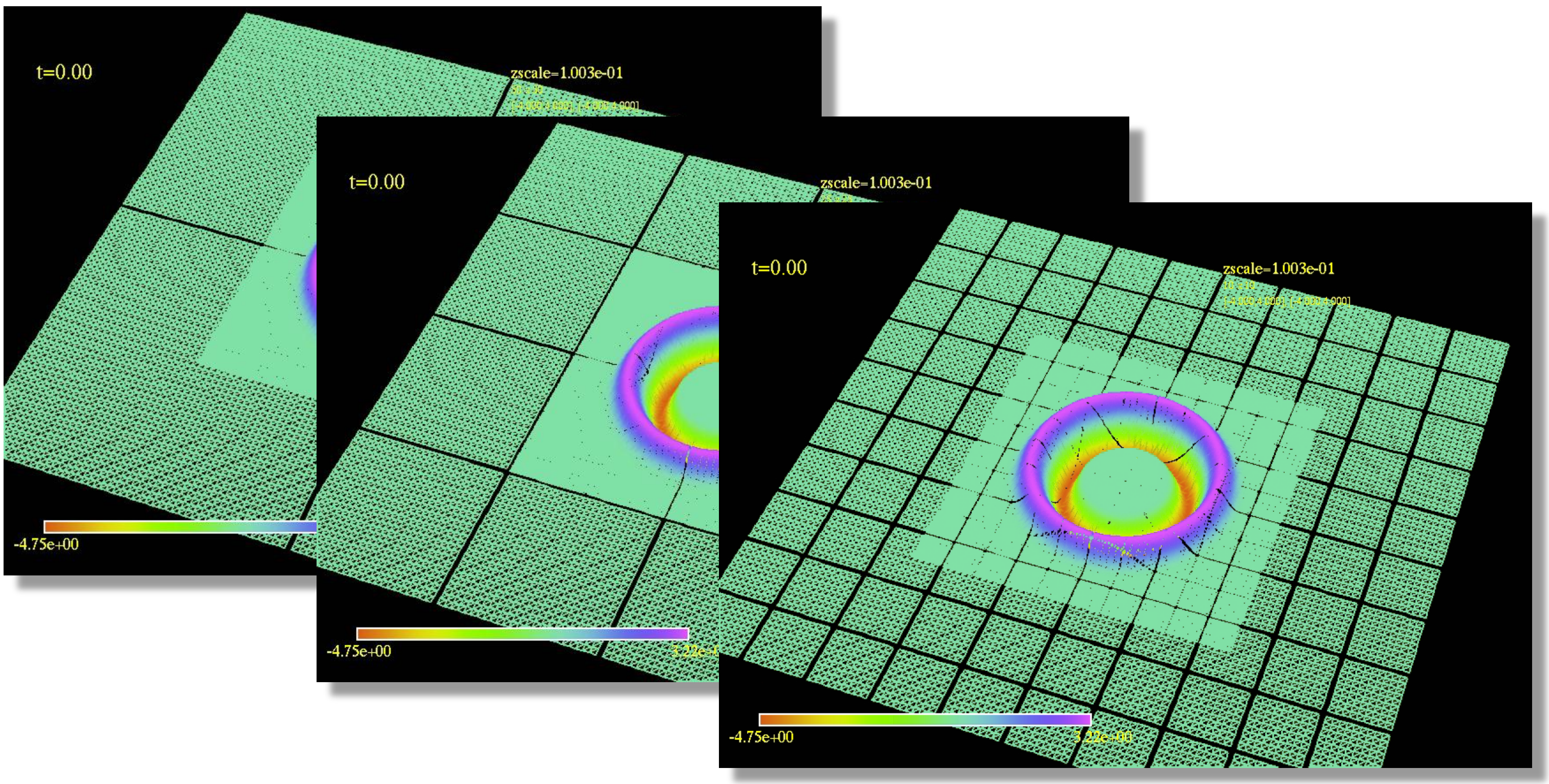
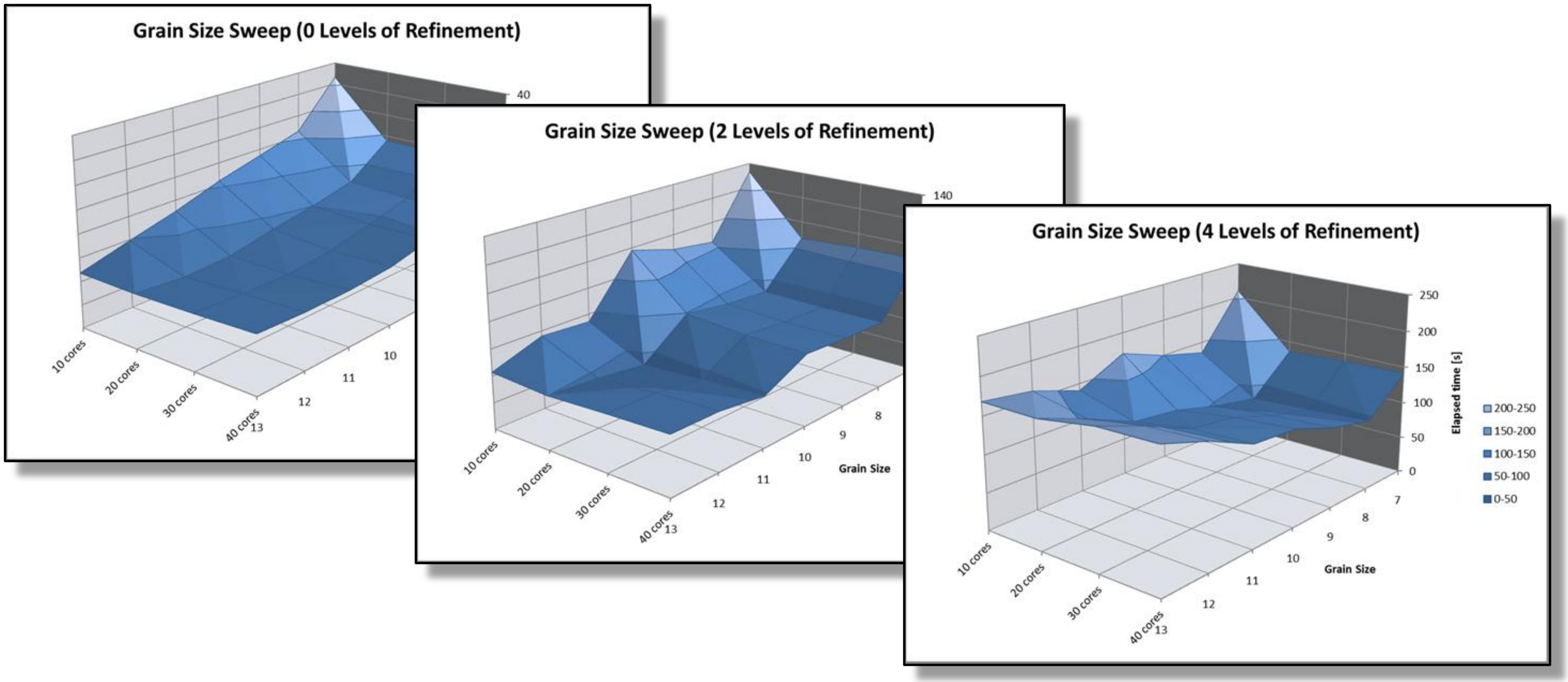


Grain Size: The New Freedom

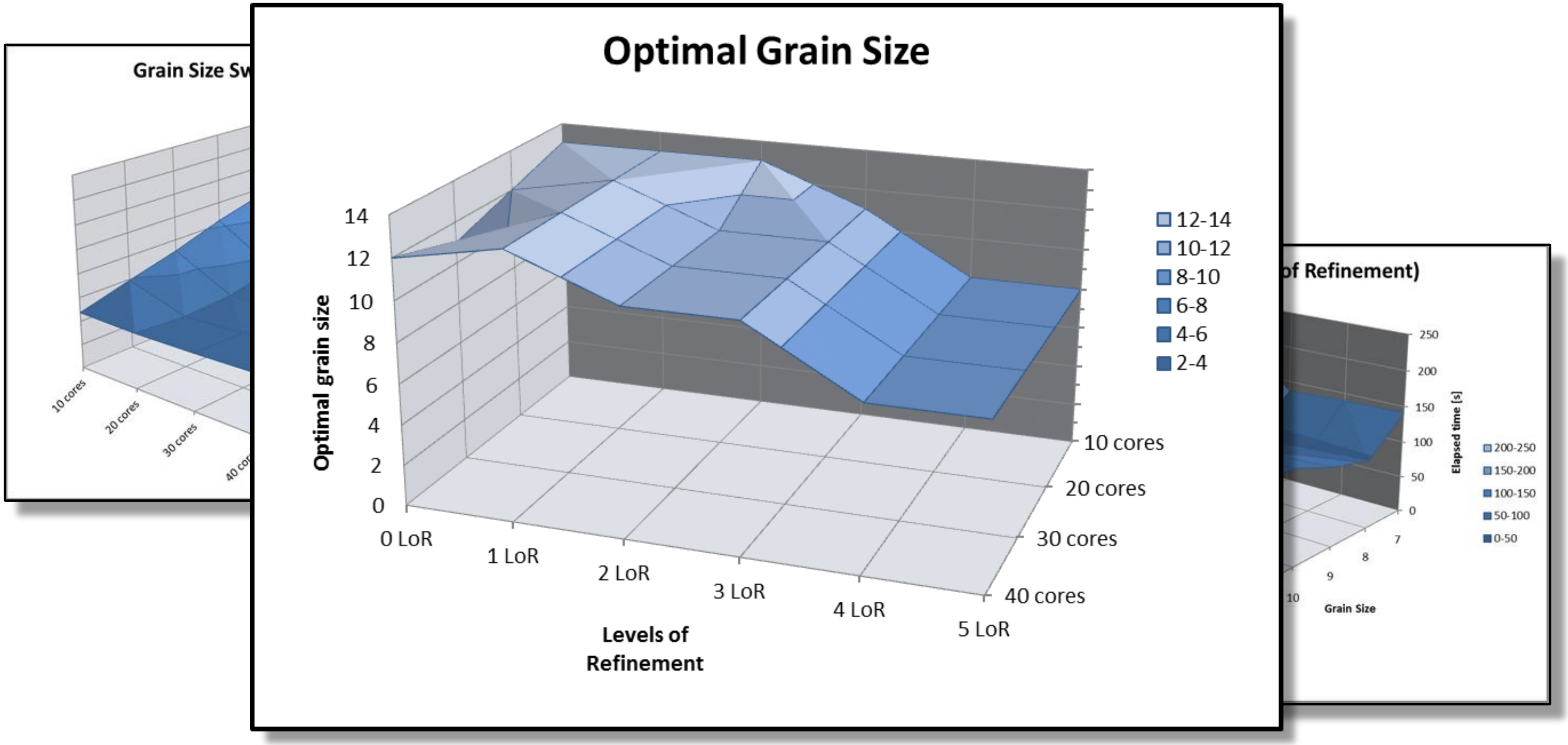


Overhead: Load Balancing



Competing effects for optimal grain size: overheads vs. load balancing (starvation)

Overhead: Load Balancing



Competing effects for optimal grain size: overheads vs. load balancing (starvation)

Conclusions

- Are we there yet?
  - Definitely NO!
  - But very promising results supporting our claim
- Are we on a right path?
  - Definitely YES!
  - Might not be THE right path, but it's a leap
- Do we have cure for those scaling impaired applications?
  - We're not sure yet!
  - Based on results we are optimistic