DEGAS: Dynamic Exascale Global Address Space

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Mission Statement: To ensure the broad success of Exascale systems through a unified programming model that is productive, scalable, portable, and interoperable, and meets the unique Exascale demands of energy efficiency and resilience.
DEGAS Proposal: Goals and Objectives

- **Scalability:**
  - Billion-way concurrency, thousand-way on chip with new architectures

- **Programmability:**
  - Convenient programming through a global address space and high-level abstractions for parallelism, data movement and resilience

- **Performance Portability:**
  - Ensure applications can be moved across diverse machines using implicit (automatic) compiler optimizations and runtime adaptation

- **Resilience:**
  - Integrated language support for capturing state and recovering from faults

- **Energy Efficiency:**
  - Avoid communication, which will dominate energy costs, and adapt to performance heterogeneity due to system-level energy management

- **Interoperability:**
  - Encourage use of languages and features through incremental adoption
Two Distinct Parallel Programming Questions

• What is the parallel control model?
  - data parallel (single thread of control)
  - dynamic threads
  - single program multiple data (SPMD)

• What is the model for sharing/communication?
  - shared memory
  - message passing
  - synchronization may be coupled (implicit) or separate (explicit)
Applications Drive New Programming Models

Message Passing Programming
Divide up domain in pieces
Compute one piece and exchange
*MPI, and many libraries*

Global Address Space Programming
Each start computing
Grab whatever / whenever
*UPC, CAF, X10, Chapel, Fortress, Titanium, GlobalArrays*
Mechanisms, not Policies

PGAS + Mixins
Goal: Programmability of exascale applications while providing scalability, locality, energy efficiency, resilience, and portability

- **Implicit constructs**: parallel multidimensional loops, global distributed data structures, adaptation for performance heterogeneity
- **Explicit constructs**: asynchronous tasks, phaser synchronization, locality

Built on scalability, performance, and asynchrony of PGAS models

- Language experience from UPC, Habanero-C, Co-Array Fortran, Titanium

Both intra and inter-node; focus is on node model
Languages demonstrate DEGAS programming model

- **Habanero-UPC**: Habanero’s intra-node model with UPC’s inter-node model
- **Hierarchical Co-Array Fortran (CAF)**: CAF for on-chip scaling and more
- **Exploration of high level languages**: E.g., Python extended with H-PGAS

Language-independent H-PGAS Features:

- Hierarchical distributed arrays, asynchronous tasks, and compiler specialization for hybrid (task/loop) parallelism and heterogeneity
- Semantic guarantees for deadlock avoidance, determinism, etc.
- Asynchronous collectives, function shipping, and hierarchical places
- End-to-end support for asynchrony (messaging, tasking, bandwidth utilization through concurrency)
- Early concept exploration for applications and benchmarks
Goal: massive parallelism, deep memory and network hierarchies, plus functional and performance heterogeneity

- **Fine-grained task and data parallelism:** enable performance portability
- **Heterogeneity:** guided by functional, energy and performance characteristics
- **Energy efficiency:** minimize data movement and hooks to runtime adaptation
- **Programmability:** manage details of memory, heterogeneity, and containment
- **Scalability:** communication and synchronization hiding through asynchrony

**H-PGAS into the Node**

- Communication is all data movement

**Build on code-generation infrastructure**

- ROSE for H-CAF and Communication-Avoidance optimizations
- BUPC and Habanero-C; Zoltan
- Additional theory of CA code generation

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DEGAS: Communication-Avoiding Compilers

XStack Review 9
Approach: “Rethink” algorithms to optimize for data movement

- New class of communication-optimal algorithms
- Most codes are not bandwidth limited, but many should be

Challenges: How general are these algorithms?

- Can they be automated and for what types of loops?
- How much benefit is there in practice?
DEGAS: Adaptive Runtime Systems (ARTS)

Goal: Adaptive runtime for manycore systems that are hierarchical, heterogeneous and provide asymmetric performance

- **Reactive and proactive control** for utilization and energy efficiency
- **Integrated tasking and communication**: for hybrid programming
- **Sharing of hardware threads**: required for library interoperability

Novelty: scalable control; integrated tasking with communication

- **Adaptation**: Runtime annotated with performance history/intentions
- **Performance models**: guide runtime optimizations, specialization
- **Hierarchical**: resource / energy
- **Tunable control**: Locality / load balance

Leverages: existing runtimes

- **Lithe** scheduler composition; **Juggle**
- **BUPC** and **Habanero-C** runtimes
Management of critical resources will be more important:

• **Memory and network bandwidth limited** by cost and energy
• **Capacity limited at many levels:** network buffers at interfaces, internal network congestion are real and growing problems

Can runtimes manage these or do users need to help?

• Adaptation based on history and (user-supplied) intent?
• Where will bottlenecks be for a given architecture and application?

Resource management is complicated. Progress, deadlock, etc. are much more complex (or expensive) in distributed memory
Lithe Scheduling Abstraction: “Harts”: Hardware Threads

- **Merged** resource and computation abstraction.

- More accurate resource abstraction.
- Let apps provide own computation abstractions

POSIX Threads

- App 1
- App 2
- Virtualized Threads
- OS
  - 0
  - 1
  - 2
  - 3
  - Hardware

Harts

- Hardware Partitions
  - App 1
  - App 2
- OS
  - 0
  - 1
  - 2
  - 3
  - Hardware

Harts (HW Thread Contexts)
Goal: Maximize bandwidth use with lightweight communication

- **One-sided communication:** to avoid over-synchronization
- **Active-Messages:** for productivity and portability
- **Interoperability:** with MPI and threading layers

Novelty:

- **Congestion management:** for 1-sided communication with ARTS
- **Hierarchical:** communication management for H-PGAS
- **Resilience:** globally consistent states and fine-grained fault recovery
- **Progress:** new models for scalability and interoperability

Leverage GASNet (redesigned)

- Major changes for on-chip interconnects
- Each network has unique opportunities
**Goal:** Provide a resilient runtime for PGAS applications

- Applications should be able to customize resilience to their needs,
- Resilient runtime that provides easy-to-use mechanisms

**Novelty:** Single analyzable abstraction for resilience

- PGAS Resilience consistency model
- Directed and hierarchical preservation
- Global or localized recovery
- Algorithm and system-specific detection, elision, and recovery

**Leverage:** Combined superset of prior approaches

- Fast checkpoints for large bulk updates
- Journal for small frequent updates
- Hierarchical checkpoint-restart
- OS-level save and restore
- Distributed recovery
1. **How to define consistent (i.e. allowable) states in the PGAS model?**

   Theory well understood for fail-stop message-passing, but not PGAS.

2. **How do we discover consistent states once we've defined them?**

   *Containment* domains offer a new approach, beyond conventional *sync-and-stop algorithms*.

3. **How do we reconstruct consistent states after a failure?**

   *Explore low overhead* techniques that minimize effort required by applications programmers.

   Leverage BLCR, GASnet, Berkeley UPC for development, and use Containment Domains as prototype API for requirements discovery.
DEGAS: Energy and Performance Feedback

Goal: Monitoring and feedback of performance and energy for online and offline optimization
- Collect and distill: performance/energy/timing data
- Identify and report bottlenecks: through summarization/visualization
- Provide mechanisms: for autonomous runtime adaptation

Novelty: Automated runtime introspection
- Provide monitoring: power / network utilization
- Machine Learning: identify common characteristics
- Resource management: including dark silicon

Leverage: Performance / energy counters
- Integrated Performance Monitoring (IPM)
- Roofline formalism
- Performance/energy counters
Resilience Support - Containment Domains + BLCR

Dynamic Control System

Proxy Applications, Numerical Libraries
- PyGAS
- Habanero-UPC
- H-CAF
- Python
- SEJITS
- ROSE
- Berkeley UPC

Energy / Performance Feedback - IPM, Roofline

GASNet-EX - Communication

ARTS - Adaptive Run-Time System

Lithe - Resource Mgmt.

Task Dispatch
- Hardware Threads
- Accelerator Cores
- General Purpose Cores
- Network Interface & I/O
DEGAS Pieces of the Puzzle

Communication-Avoiding optimization in Rose

Containment Domains with state capture

GASNet-EX to avoid synchronization

Lithe for managing hardware threads

H-PGAS (C/F) for generating DSL code; intra node locality management
Team Members

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DEGAS Retreats Highlight and Encourage Integration

- Semi-annual 2-day meeting of entire team, stakeholders
  - Application and Vendor Advisory groups
- Updates on progress, open problems, plans
- Demos showing integration of tools and driving applications
- Enforces teamwork, demos for milestones and progress metrics
- Feedback from team and stakeholders to refine goals and effort
- Long tradition of retreats at UC Berkeley
  - Many successful large projects (from RAID to ParLab)