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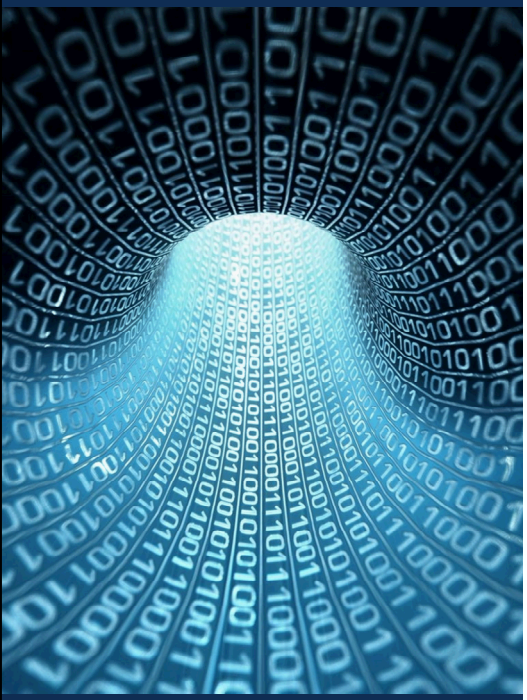

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# The DHARMA Approach to Asynchronous Many-Task Programming

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PSAAP-West

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# What are core requirements for next-generation applications?

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- An abstraction layer between applications and the runtime system/physical architecture
- An implementation of a software stack that supports this abstraction layer
- Community best practices and eventual standards for this abstraction layer

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The DHARMA project at Sandia performs AMT runtime system R&D to address these core application requirements

# Asynchronous Many-Task (AMT) runtimes address key performance challenges posed by future architectures

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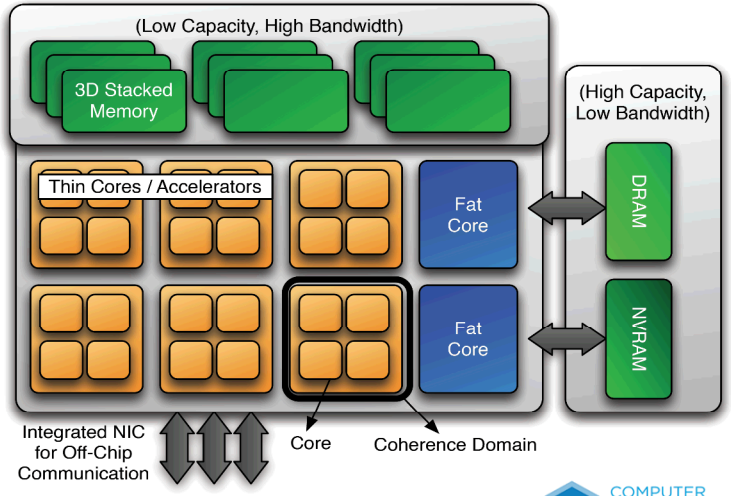
- Performance challenges:
  - Utilizing whole machine requires more parallelism
  - Managing deep memory hierarchies requires flexible staging of data/assigning work
  - Handling dynamic workloads requires flexible task scheduling

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COMPUTER ARCHITECTURE LABORATORY
EXASCALE DESIGN SPACE EXPLORATION

- **Asynchronous**: express all possible parallelism and minimize/hide communication/scheduling latency
- **Many-Task**: Chunks of work of ``correct'' granularity that can be flexibly assigned to different memory/execution spaces

# Sandia led a comparative analysis study of leading AMT runtimes to inform our technical roadmap

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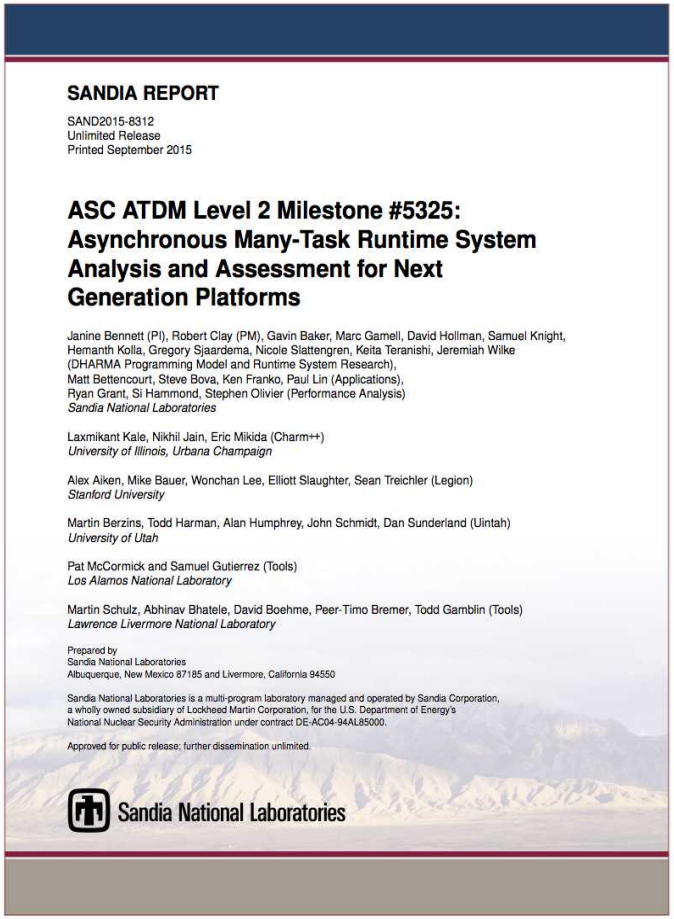
- Broad survey of many AMT runtime systems
- Deep dive on Charm++, Legion, Uintah
- Programmability
  - Does this runtime enable efficient expression of our workloads?
- Performance
  - How performant is this runtime for our workloads on current platforms?
  - How well suited is this runtime to address exascale challenges?
- Mutability
  - What is the ease of adopting this runtime and modifying it to suit our needs?



**SANDIA REPORT**

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**ASC ATDM Level 2 Milestone #5325: Asynchronous Many-Task Runtime System Analysis and Assessment for Next Generation Platforms**

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# Lessons learned from study led to application-driven programming model specification co-design effort

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- Data, task, and pipeline parallelism can be expressed in different ways
  - Explicit parallelism vs apparently sequential semantics
  - Arbitrary data structures vs strong data model
  - Runtime vs user-level control
  - New language vs embedded in C/C++
- Model should enhance performance, productivity, resilience
  - Applications should not be (much) more difficult to write than MPI
  - Make difficult things more tractable, e.g. load balancing fault-tolerance
- Design space tradeoffs need further assessment prior to committing to a single runtime
  - Across variety of applications and architectures
  - Further research required in some aspects of runtime (e.g., resource management)

# What do we mean by "application-driven co-design of a programming model specification"?

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- Runtimes can be decomposed into a specification and implementation
  - The specification is formal documentation that
    - Provides abstractions for expressing what an application does (i.e., the programming model)
    - Can express correctness requirements
    - Can express performance requirements
  - The implementation maps specification requirements onto specific operations/events
- We are co-designing an AMT programming model specification with application and runtime developers
  - Meet our application requirements
  - Generate the runtime requirements

# DHARMA software stack separates policy and mechanism

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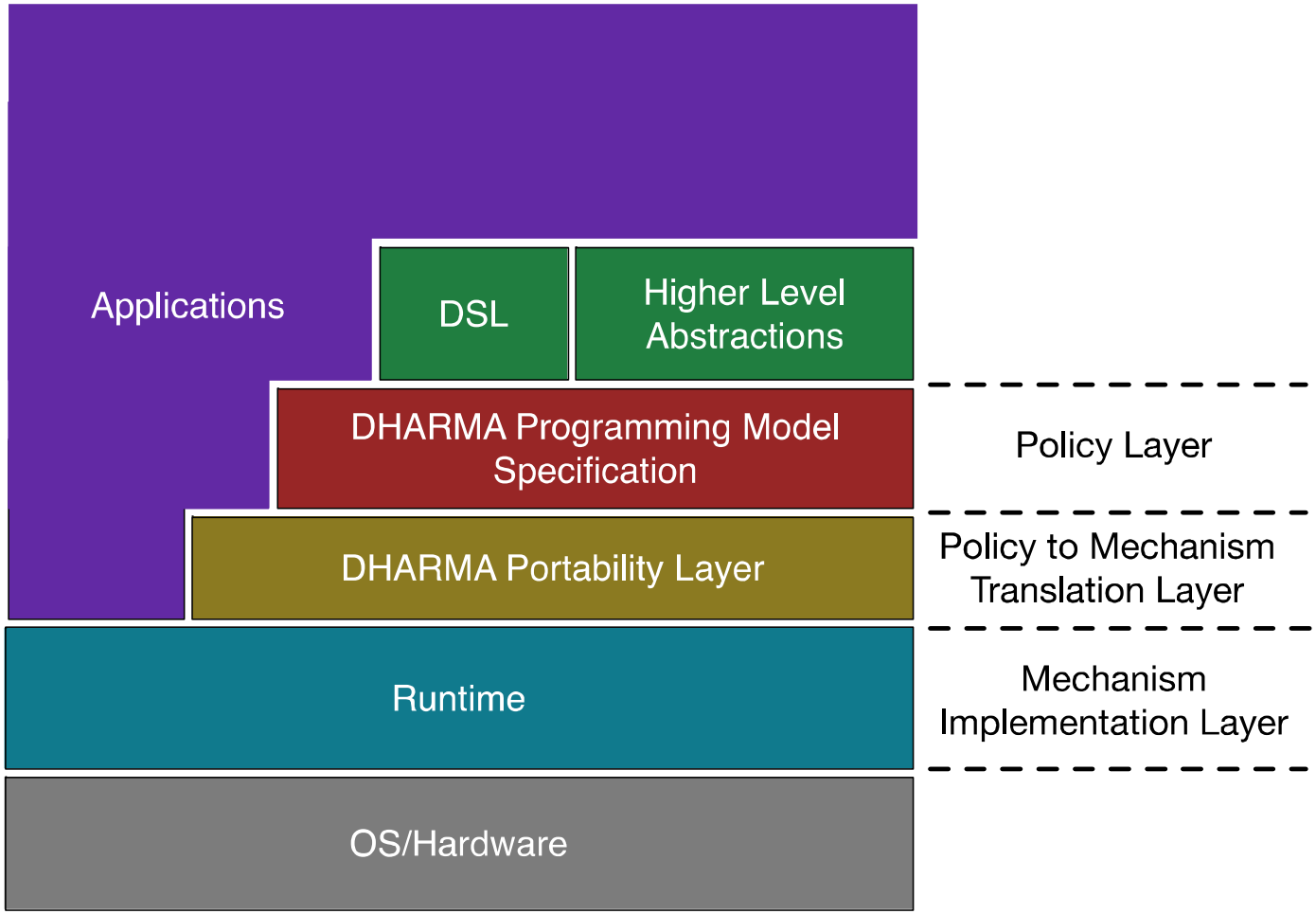

# Expression of policy enables runtime freedom to make complex performance-oriented decisions

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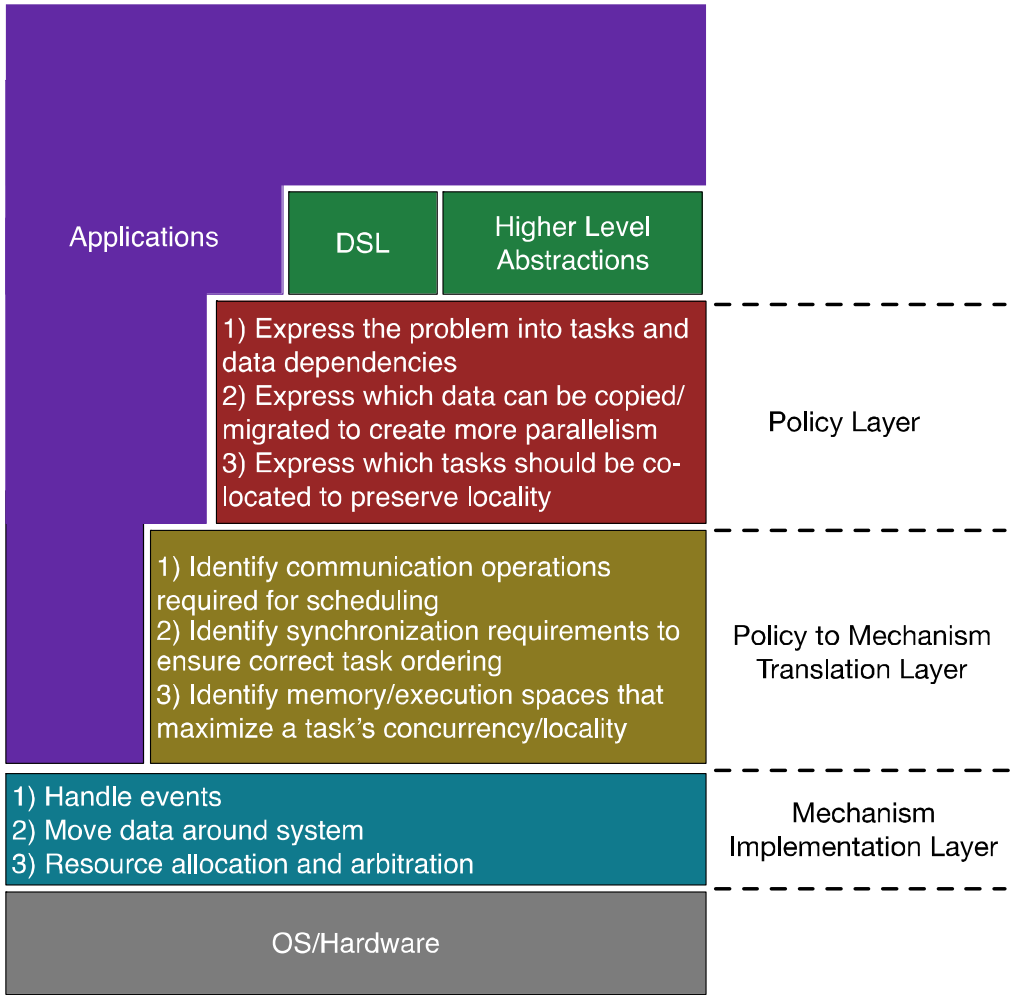
## Design Intent:

- Applications specify policy
  - Enable rapid development of correct implementation
- Applications can specify mechanism
  - Enable improvement towards performant implementation



# The separation of policy and mechanism facilitates exploration of runtime design space

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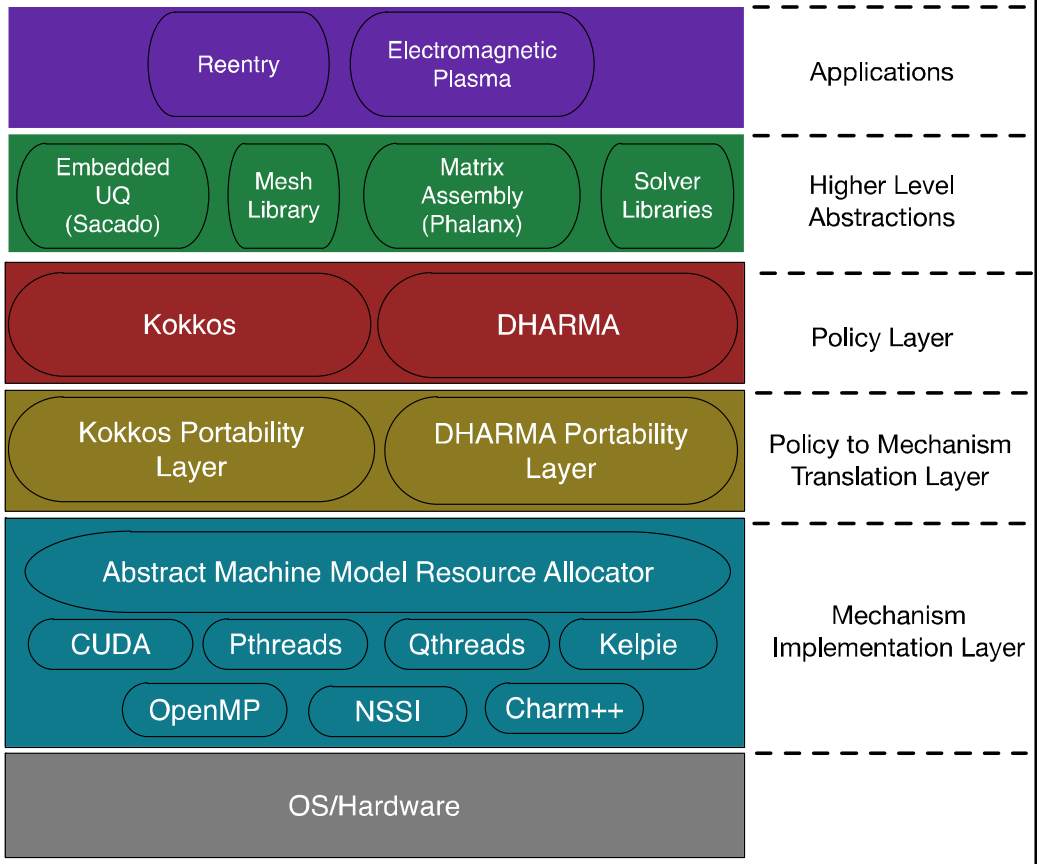
- AMT software stack working group at Sandia
  - DHARMA
  - Kokkos
  - Data Warehouse/Kelpie
  - Resource allocation and management
  - Qthreads
- Initial implementation of stack this year leveraging Charm++
- Working with community to explore alternative stack implementations
  - OCR, REALM

Sample Sandia Software Stack



# Application requirements shape the initial programming model specification

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- Application controls initial problem decomposition and distribution
- Runtime should support
  - Efficient SPMD launch and coordination semantics
  - Collectives
  - Basic checkpoint/restart fault recovery supported
  - Replay of tasks for ease of debugging
  - Application-specific data structures/layouts
  - Expression of all forms of parallelism (data, pipeline, task)
- Embed in C++

# The DHARMA programming model specification is a set of parallel semantics embedded in C++ syntax

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- Declarative, not procedural imperative
- Coordination semantics replace explicit send/recv
- Enqueue work to be performed instead of explicitly (imperatively) doing work immediately or blocking
- As much as possible, preserve sequential semantics to simplify reasoning about code correctness
- *Use standard C++ constructs* (e.g., reference-counted pointers) to manage parallelism
- Do not need to know C++11 to code
  - Works with gcc >= 4.7, clang >= 3.5

# The DHARMA project has three closely-coupled key activities

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- Co-design AMT programming model specification
  - Gather application requirements for programming model/runtime
  - Assess what runtime requires programming model/application to express
- Implement specification
  - Leverage existing efforts
  - Encourage vendor involvement
- Work with community to define best practices and eventual standards for AMT
  - Collaborating with Tim Mattson's team at Intel on DHARMA programming model specification
  - Recurring engagement with Charm++, OCR, Legion teams

Let us know if you are interested in collaborating in any of these areas!