The Morphware Stable Interface: A Software Framework for Polymorphous Computing Architectures

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Acknowledgements

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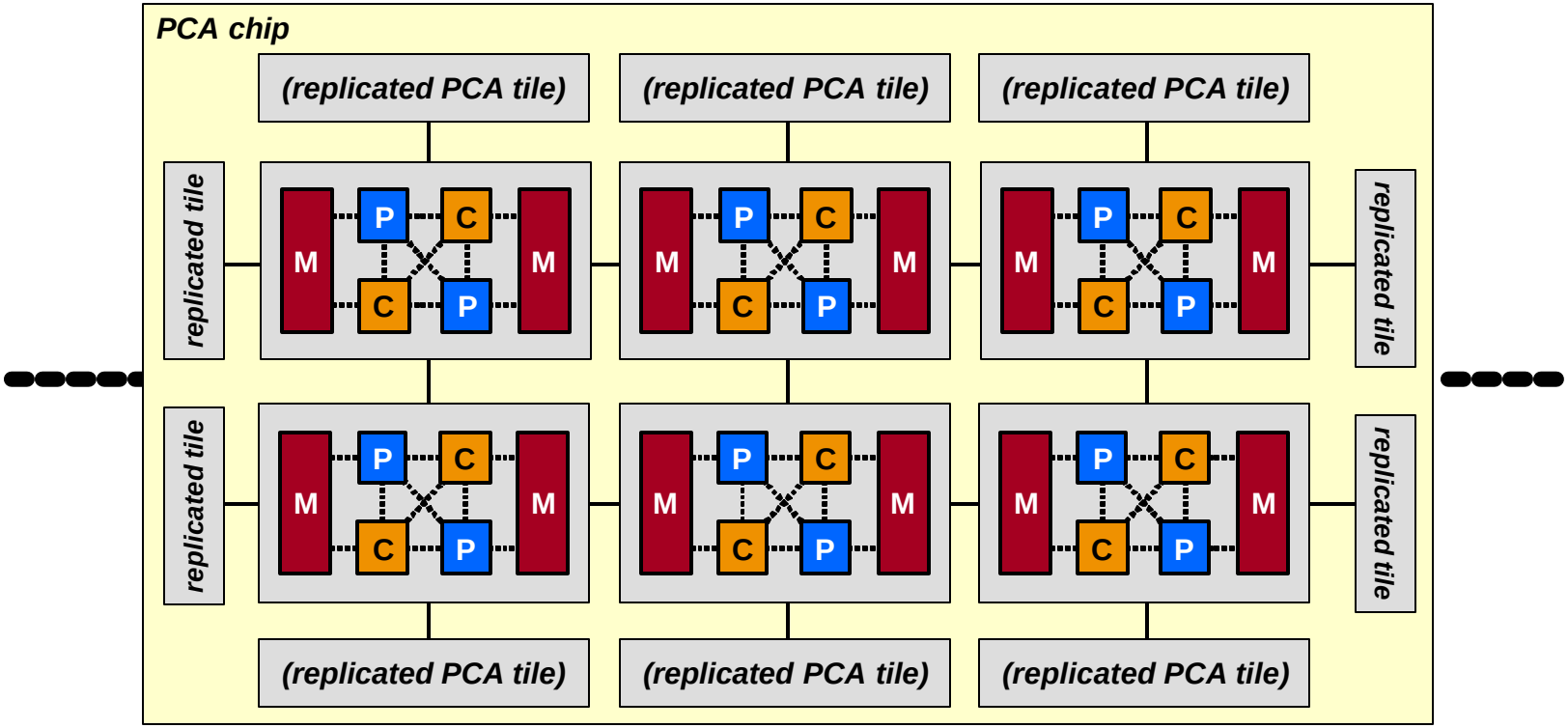
Polymorphous Computing Architectures

- **DARPA effort for high performance embedded platforms with strong, rapid, reactive in-mission configurability**
  - **Support dynamic and multi-mission requirements**
  - **Support collaborative, information-centric missions**
- **PCA will develop processing architectures that "morph"**
  - **Hardware and software resources reconfigure to balance resource requirements and availability**
    - **at multiple levels: micro-architecture, network, system**
    - **at multiple time scales: in-mission, between-mission**

Generic PCA Microarchitecture



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Generic PCA Microarchitecture

- **Tiled structure**
  - **Fully capable computing cores**
  - **Configurable memory and cache**
  - **Configurable data paths, network interfaces, and I/O**
  - **Streaming and Threaded modes**
  - **Methods to aggregate tiles into larger processing units**
- **Core projects differ in**
  - **aggregation mechanisms**
  - **relative emphasis on processor, memory, or comm design**
- **Performance on the order of (per chip)**
  - **4 – 64 GFLOPS / 4 – 16 GOPS**
  - **25 – 32 GB/s off-chip I/O**

Software and PCA

- **Increased hardware flexibility and complexity brings increased software complexity**
  - **If we build target platform reconfigurability and performance info into the application, we lose scalability and portability**
  - **If we don't, the build and run-time systems will be entirely responsible for leveraging the platform capability, and we still lose fine-grain morphability**
  - **Applications must be reactive to feedback from the hardware**
    - **resource collisions, SWEPT, faults**
- **Solution: the Morphware Stable Interface (MSI)**

The Morphware Stable Interface (MSI)

- **Application Development Framework for PCAs**
- **Comprised of a software architecture and a suite of open standard APIs**
- **Goals**
  - **Dynamically optimize PCA resources for application functionality, service requirements, and constraints**
  - **Obtain nearly optimal performance from PCA hardware**
  - **Be highly reactive to PCA hardware and user inputs**
  - **Manage PCA software complexity**
  - **Leverage existing and already-developing technologies**
- **Cross-project effort, developed in parallel with the hardware**

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The Morphware Forum

- Informal consortium of the PCA contractors and other selected participants
- Organized and led by the Georgia Tech/SPAWAR team
- Meets quarterly
  - interim meetings and activities as required
- Propose, debate, develop, test, validate, document, and demonstrate standards that define the MSI

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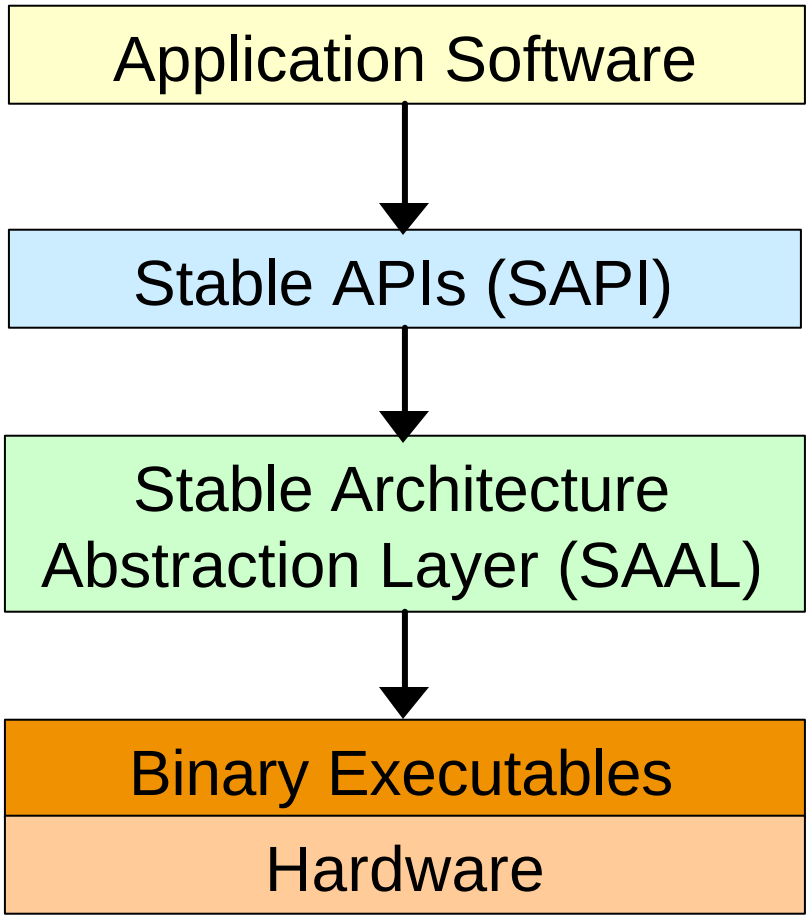
The Morphware Forum

- Applied Photonics
- Georgia Institute of Technology
- George Mason University
- IBM
- Lockheed Martin Company
- Massachusetts Institute of Technology
- MIT/Lincoln Laboratory
- Mercury Computing Systems
- Mississippi State University
- MPI Software Technology, Inc.
- Northrup Grumman
- Reservoir Labs, Inc.
- Raytheon
- SPAWAR
- South West Research
- Stanford University
- University of Texas - Austin
- University of Illinois
- University of Pennsylvania
- University of Southern California
- Vanderbilt University

Dual Portability Layers



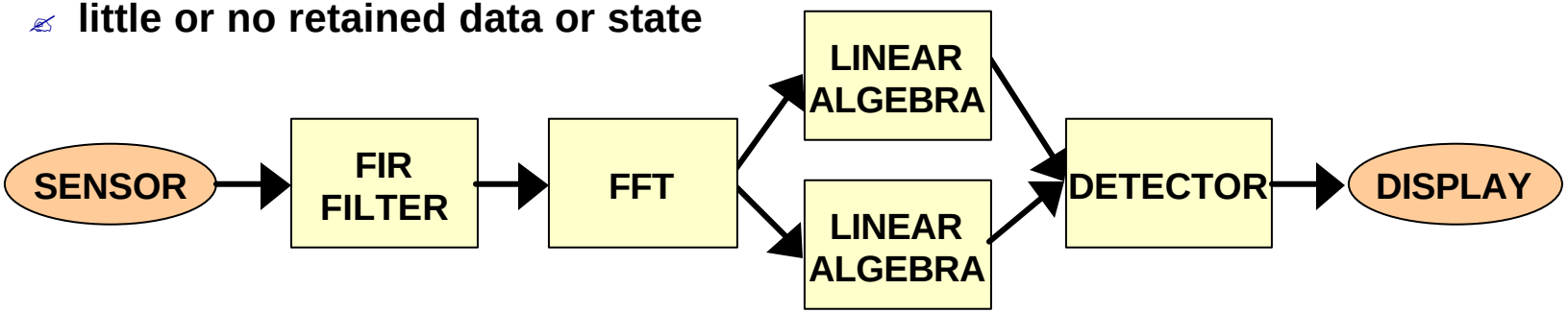
- **Stable API (SAPI) and Stable Architecture Abstraction Layer (SAAL) provide dual portability layers**
- **Application SW describes functionality, constraints, and performance requirements**
- **SAPI is PCA-aware collection of standardized language and service APIs**
- **SAAL is PCA-aware abstracted low-level machine representations**

Why SAAL?

- Traditional languages based on a machine model increasingly incorrect
  - Single program counter
  - One operation at a time
  - Data universally local
- All modern high performance computing systems battling this issue
- In order to exploit new hardware, core teams developed new languages not based on old model
- New languages based on similar models
- Formalize the models to make it explicit

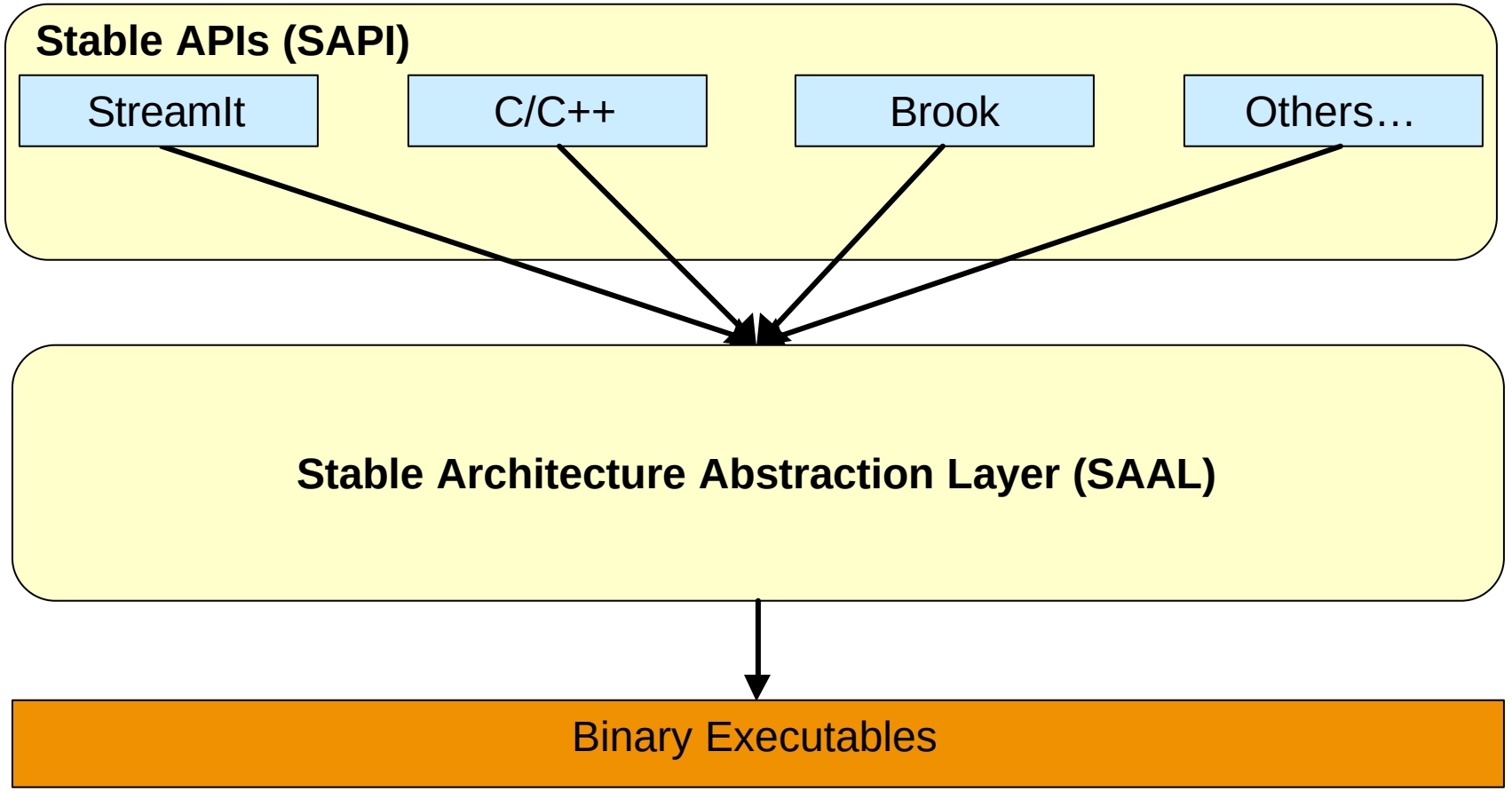
Stream Languages

- Compute-intensive portions of many applications have characteristics of stream operations
  - fixed data flow graph
  - large, possibly infinite, data stream
  - functional kernels not data-dependent
  - functional kernels independent of one another
  - little or no retained data or state



- Representations that enforce these characteristics ideally suit PCA architectures, aid compiler in
  - Optimization
  - Scheduling
  - Resource allocation
  - Data Locality

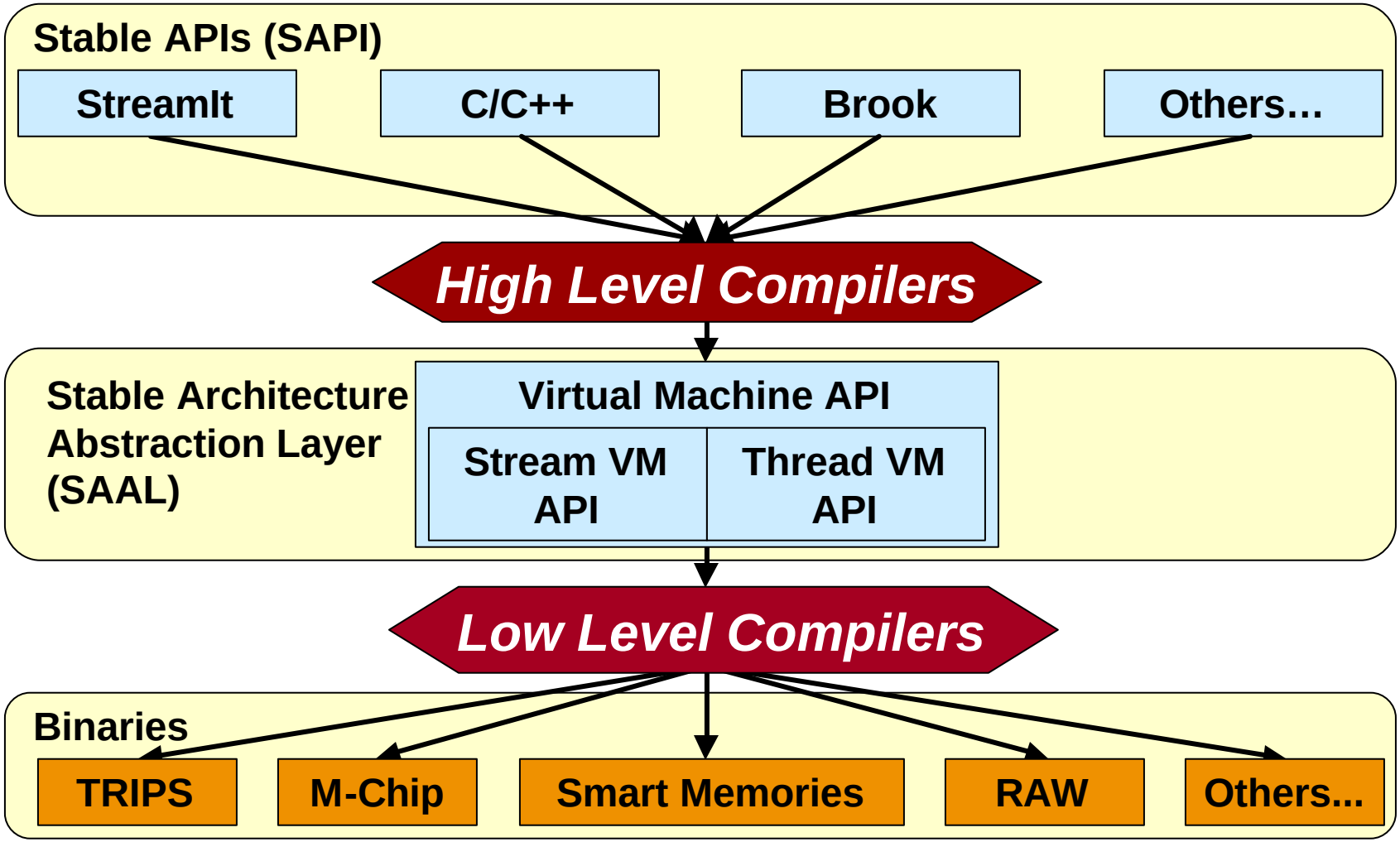
Morphware Languages



SAAL Instantiation

- Traditional languages have an implicit SAAL layer
- MSI has an explicit SAAL layer, a portable API that exposes the virtual resources typical of PCA systems
  - Sacrifices some tool chain flexibility for simpler, more defined, more analyzable build chain
  - Factors deployment of new languages and hardware
  - Allows explicit consideration of model of computer
  - Formalizes and augments existing model
- Creates a two-stage compile process
- Example constructs: kernel, stream, processor, etc

Morphware Compilation

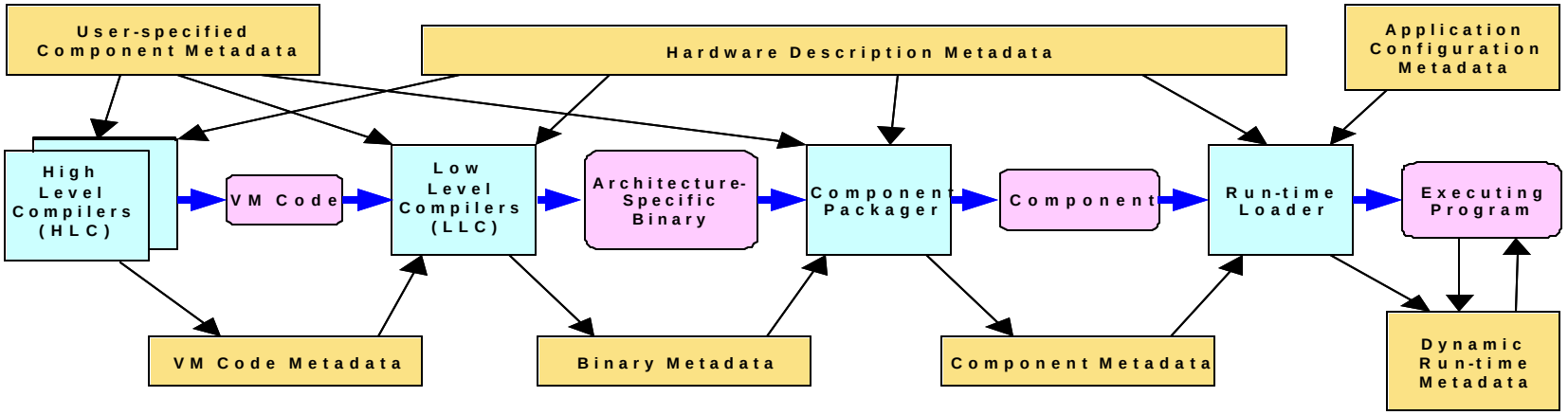


Metadata in Morphware

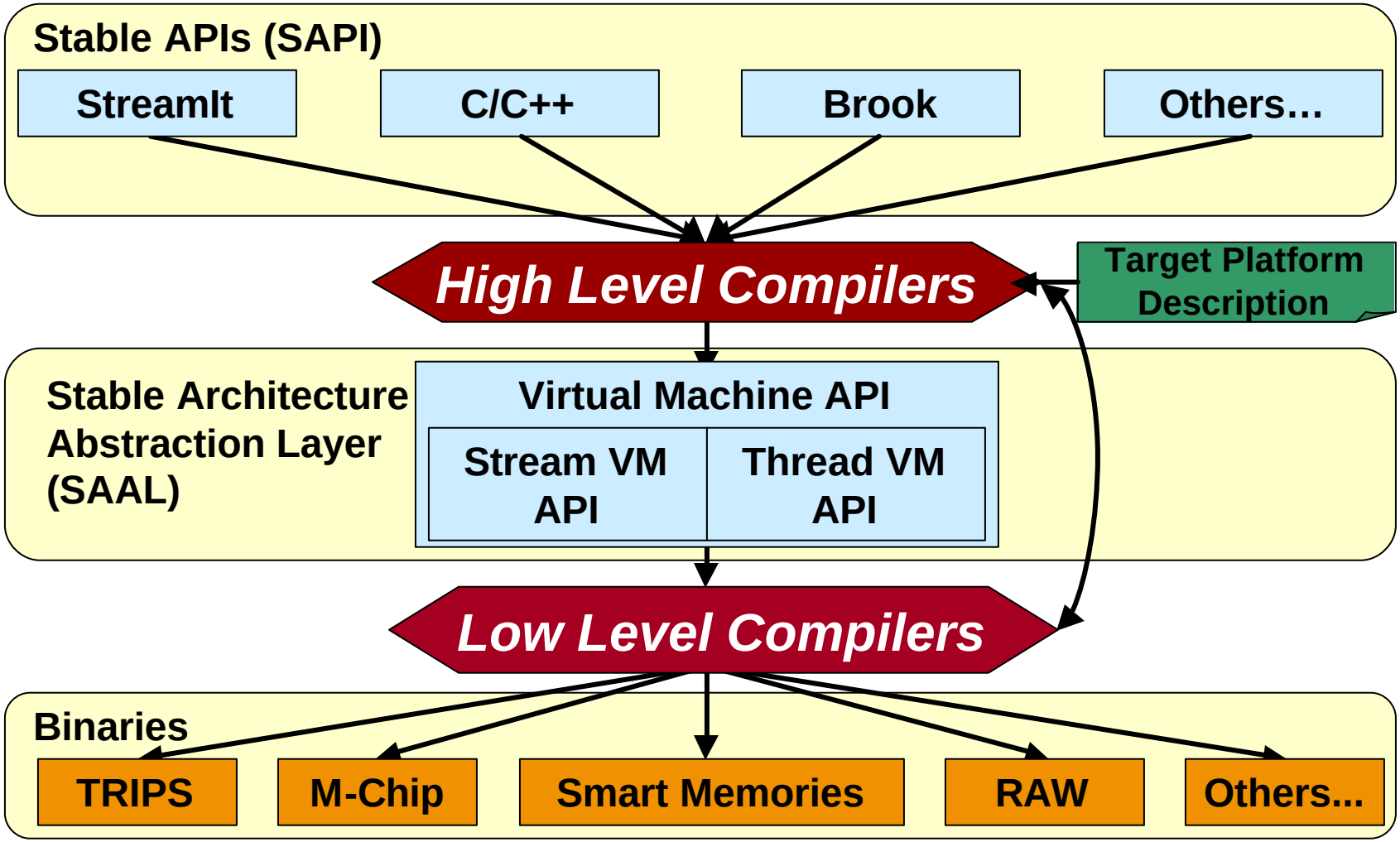
- PCA Hardware is complex and changing
- PCA Missions are complex and changing
- Large amount of configuration, constraints, requirements, etc. information in addition to functional requirement
- Extracting and encapsulating this information
  - Increases portability, scalability
  - Facilitates Reconfiguration, Repurposing, Redeployment
  - Is an important goal of most modern software systems

Metadata System

- Metadata needed throughout the PCA system
  - Several contexts
  - Consistent method of representation & query preferred
  - Needed to enable processor and compiler developers to progress
- Current system stores metadata as XML
  - Metadata is expressed as relational, hierarchical object oriented structure
  - Instantiated as XML
  - Contexts are defined by a Schema and Documentation
  - Accommodates procedural or static representation queries
  - Accessible to wide range of API's, tools, etc.



Use of Metadata



Platform Description Context

- **Needed by HLC to improve VM output**
  - **Helps allow coarse grain partitioning of applications into appropriate sized pieces**
- **Nearly complete, minor fixes remain**
- **Describes target platform using common dictionary of virtual resources and attributes**
  - **Processors: type, frequency, max-IPC, latency…**
  - **Memories: type, size, cache-linesize, associativity…**
  - **Net-Links: senders, receivers, latency, bandwidth**

Dynamic Configuration

- **Model so far good for flexible resources, goals & constraints**
  - **Two level compile**
  - **structured VM code**
  - **Well defined metadata**
  - **Good compilers**
- **Dynamic resources, goals, & constraints much harder problem**
  - **Builds have (nearly) infinite time to analyze & search the solution space, run-time changes must happen quickly**
  - **Static, configurable build parameters a hard, but tenable task**
  - **Support for dynamic criteria explodes the solution space**

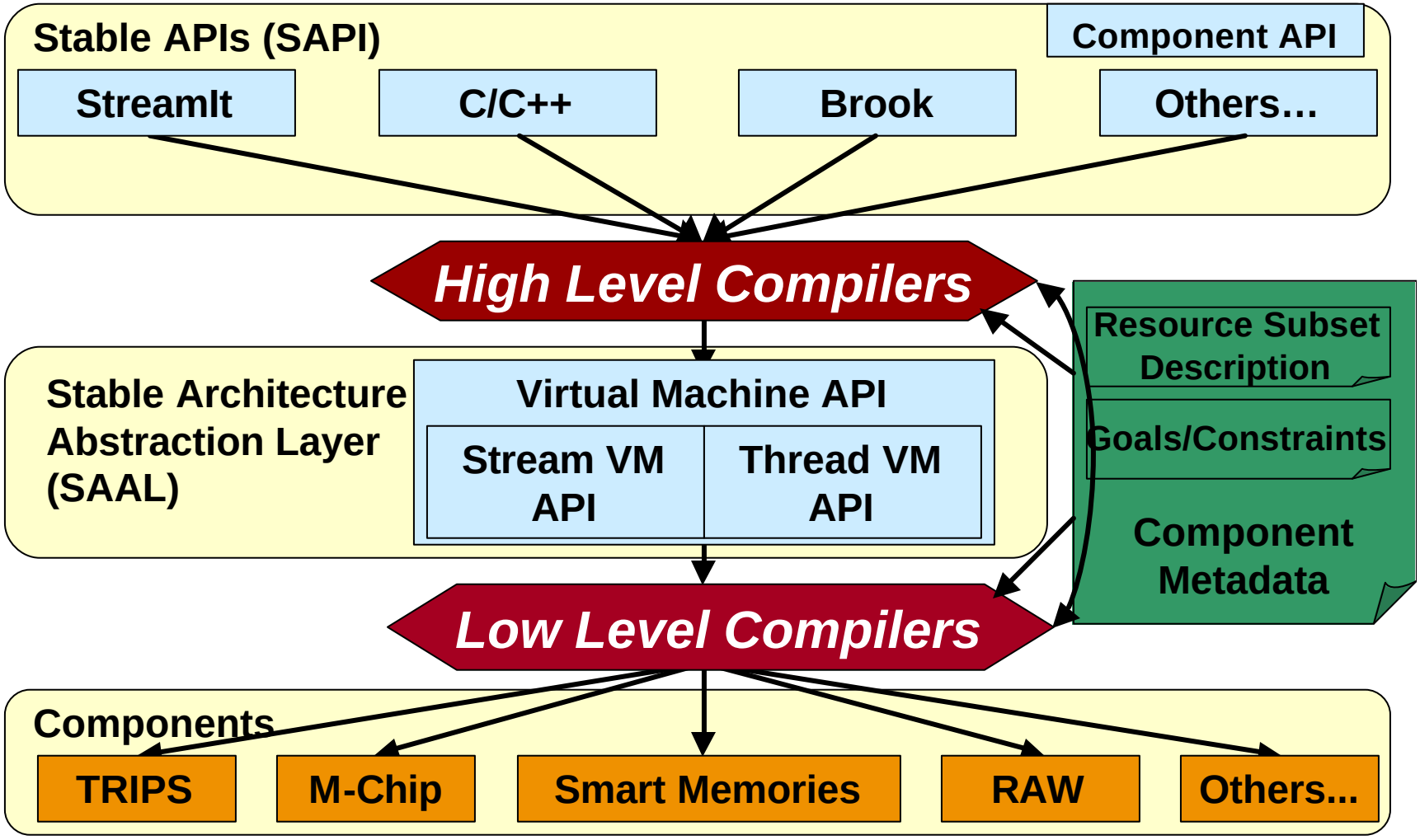
Alternate Monoliths

- **Build with several parameters**
  - Traverse build chain with a defined set of constraints, goals, resources expected
  - Deploy binaries for each set
  - Select the best-fit binary at run-time
- **Benefits**
  - Build chain sooner
  - Easier problem, faster builds
  - Known, testable states
  - Better optimization for known states
- **Problems**
  - Problems with unexpected hardware states
  - Not as flexible as the hardware
  - Only optimal for expected states

Component-Based Approach

- Flexibility & resilience gained by partitioning physical resources
- Configure each partition independently
- Build binaries for each partition in various states
- Benefits:
  - Smaller problem makes flexible build criteria more feasible
  - Hierarchical approach factors the problem of resource management
  - Able to match run-time needs more closely
  - Able to achieve top performance in more situations
  - More easily respond to hardware failures & changes
- Problems
  - Requires a more robust run-time system to fully exploit
  - Many states possible – complicates testing
  - Framework bloat

Component-Building

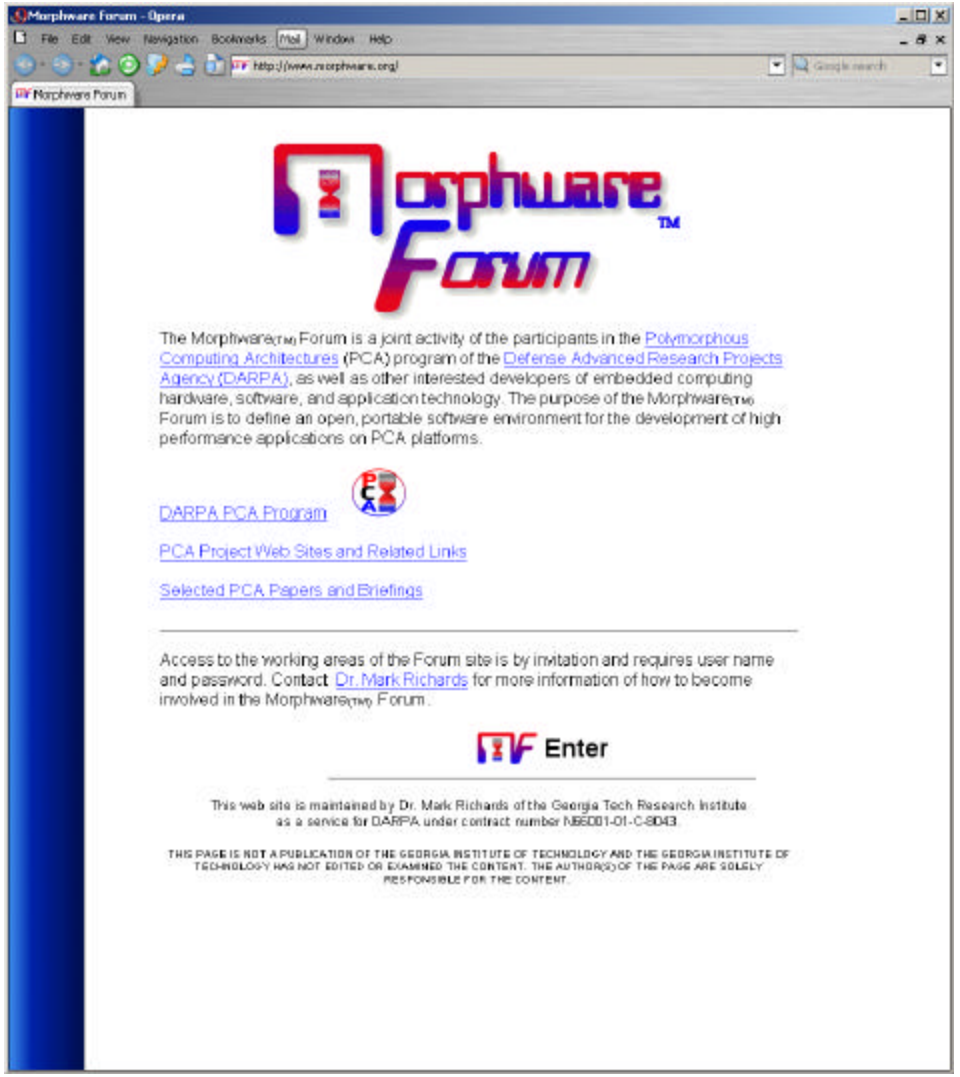


Morphware Forum Steps

- **Priority: End-to-End framework that allows an application that can reconfigure it's platform**
- **Immediate priorities:**
  - **Finish TVM**
  - **Finish HWMD**
  - **Define HLC / LLC Interaction**
  - **Determine run-time services**
    - **Load, unload, configure, measure, etc.**
  - **Consider component-based approaches**
- **Continue regular activities**
  - **Quarterly meetings, interims, draft documents, etc**

www.morphware.org

- The Morphware Forum web site provides some public information
  - Selected public papers & briefings
  - Links to PCA project sites and related links
  - Link to DARPA PCA
  - This paper and presentation, soon
- In the future, it will provide one-stop public dissemination of MSI documents



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