Operating Systems Should Manage Accelerators

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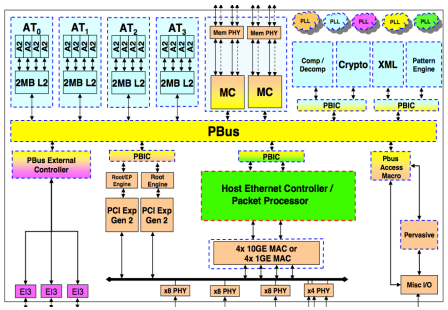
Accelerators

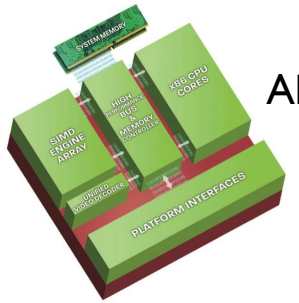
- Specialized execution units for common tasks
  - Data parallel tasks, encryption, video encoding, XML parsing, network processing etc.
- Task offloaded to accelerators
  - High performance, energy efficient (or both)

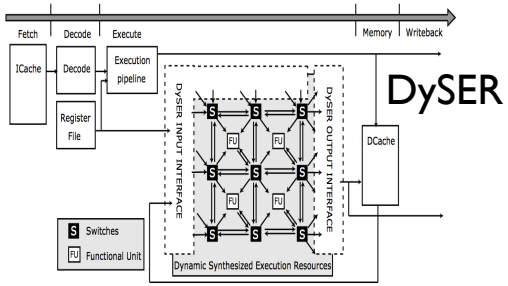
Wire speed processor



GPU

APU





DySER

Crypto accelerator

Why accelerators?

- Moore's law and Dennard's scaling
  - Single core to Multi-core
  - Dark Silicon: More transistors but limited power budget [Esmaeilzadeh et. al - ISCA '11]
- Accelerators
  - Trade-off area for specialized logic
  - Performance up by 250x and energy efficiency by 500x [Hameed et. al – ISCA '10]
- Heterogeneous architectures

Heterogeneity everywhere

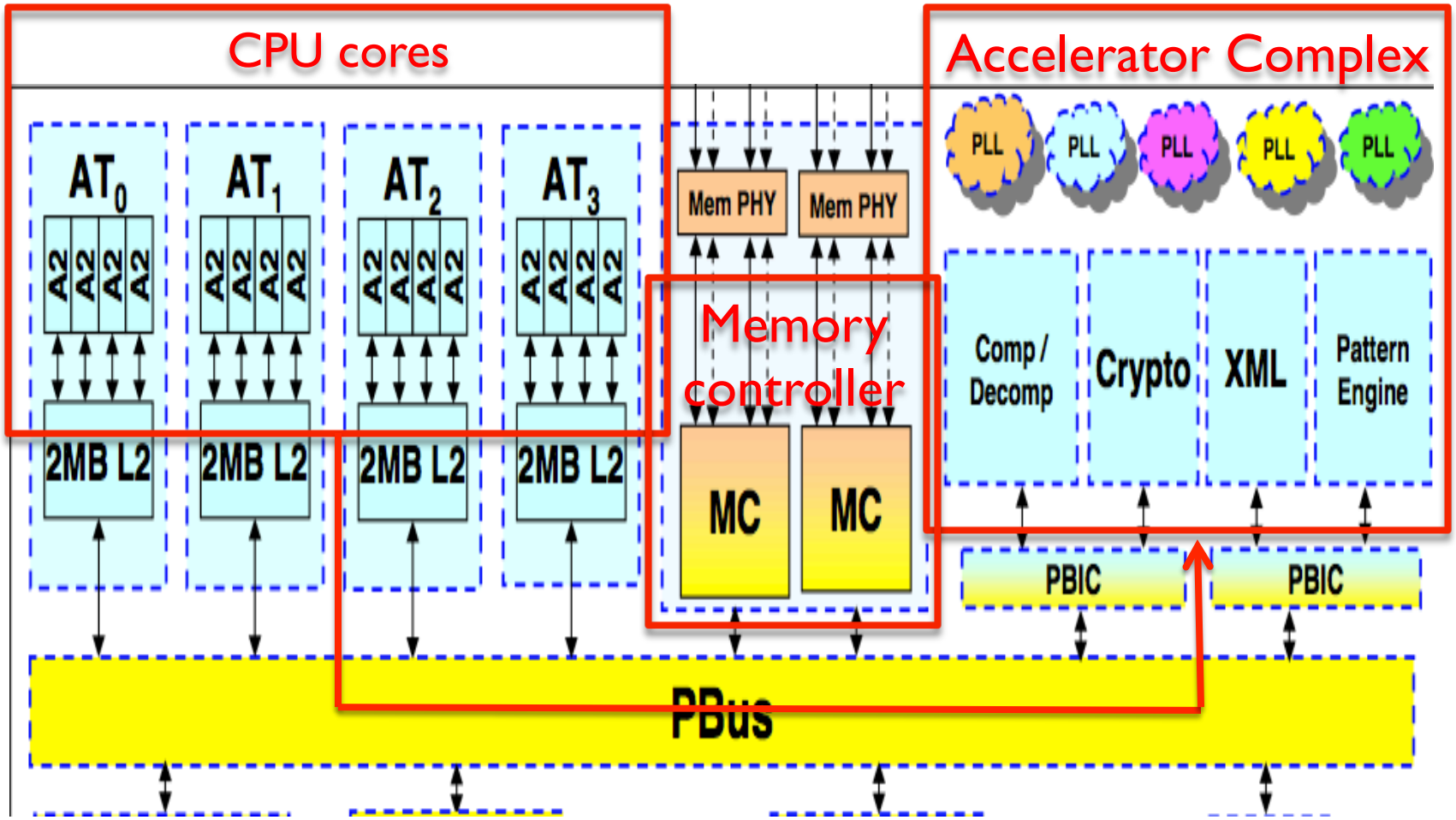
- Focus on diverse heterogeneous systems
  - Processing elements with different properties in the same system

- Our work
  - How can OS support this architecture?
    1. Abstract heterogeneity
    2. Enable flexible task execution
    3. Multiplex shared accelerators among applications

Outline

- Motivation
- Classification of accelerators
- Challenges
- Our model - Rinnegan
- Conclusion

IBM wire-speed processor



Classification of accelerators

- Accelerators classified based on their accessibility
  - Acceleration devices
  - Co-Processor
  - Asymmetric cores

Classification

Properties		Acceleration devices	Co-Processor	Asymmetric cores
Systems		GPU, APU, Crypto accelerators in Sun Niagara chips etc.	C-cores, DySER, IBM wire-speed processor	NVIDIA's Kal-El processor, Scalable cores like WiDGET
Location		Off/On-chip device	On-chip device	Regular core that can execute threads
Accessibility				
	Data	DMA or zero copy	System memory	Cache coherency
Resource contention		Multiple applications might want to make use of the device	Sharing of resource across multiple cores could result in contention	Multiple threads might want to access the special core

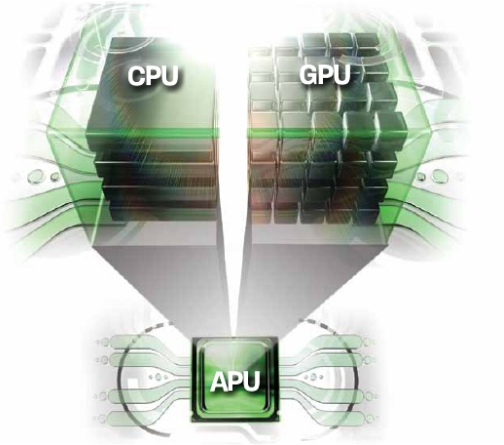
1) Application must deal with different classes of accelerators with different access mechanisms
2) Resources to be shared among multiple applications

Challenges

- Task invocation
  - Execution on different processing elements
- Virtualization
  - Sharing across multiple applications
- Scheduling
  - Time multiplexing the accelerators

Task invocation

- Current systems decide statically on where to execute the task
- Programmer problems where system can help
  - Data granularity
  - Power budget limitation
  - Presence/availability of accelerator

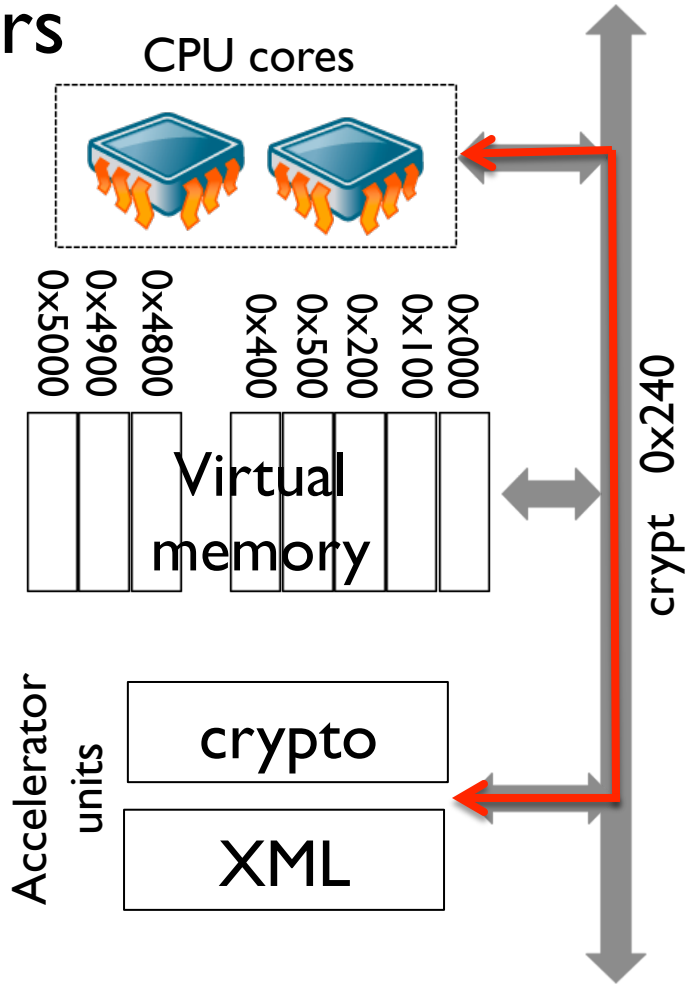


AES

Crypto accelerator

Virtualization

- Data addressing for accelerators
  - Accelerators need to understand virtual addresses
  - OS must provide virtual-address translations
- Process preemption after launching a computation
  - System must be aware of computation completion



Scheduling

- Scheduling needed to prioritize access to shared accelerators
- User-mode access to accelerators complicates scheduling decisions
  - OS cannot interpose on every request

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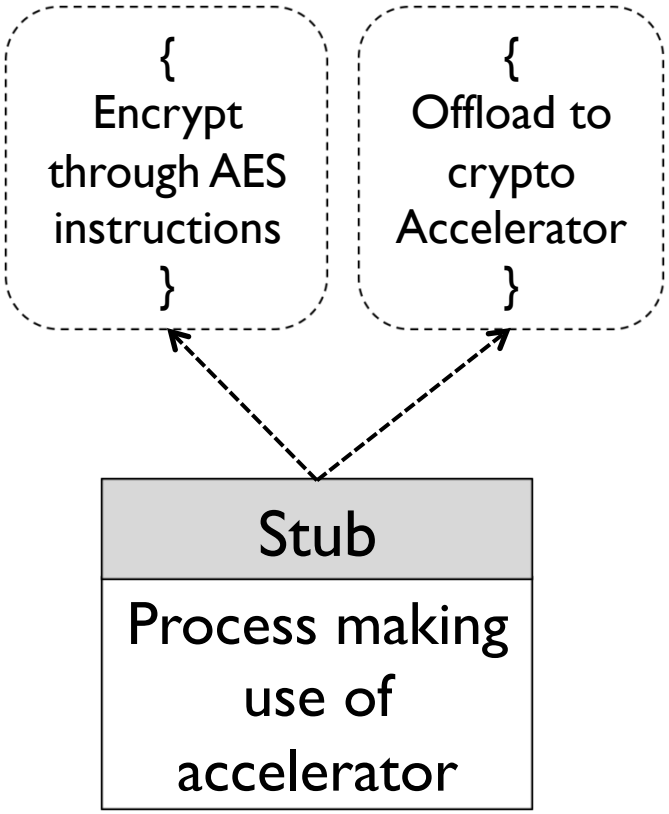
Rinnegan

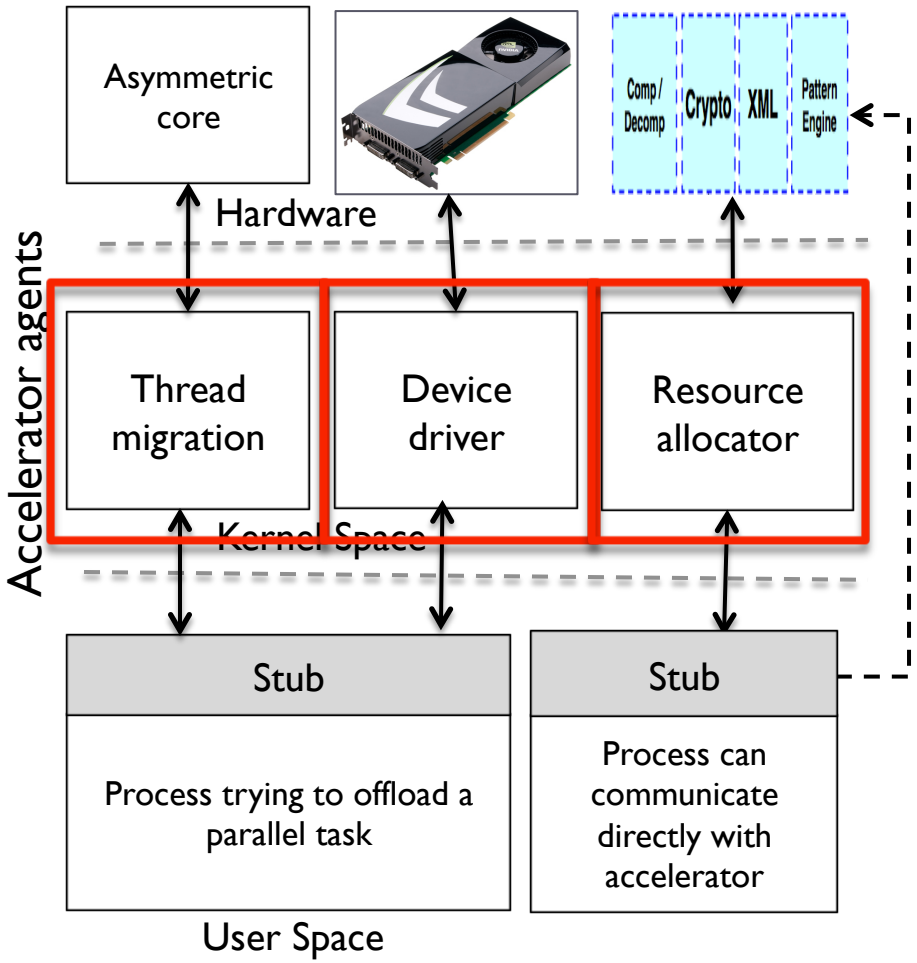
- Goals
  - Application leverage the heterogeneity
  - OS enforces system wide policies
- Rinnegan tries to provide support for different class of accelerators
  - Flexible task execution by Accelerator stub
  - Accelerator agent for safe multiplexing
  - Enforcing system policy through Accelerator monitor

Accelerator stub

- Entry point for accelerator invocation and a dispatcher
- Abstracts different processing elements
- Binding - Selecting the best implementation for the task
  - Static: during compilation
  - Early: at process start
  - Late: at call

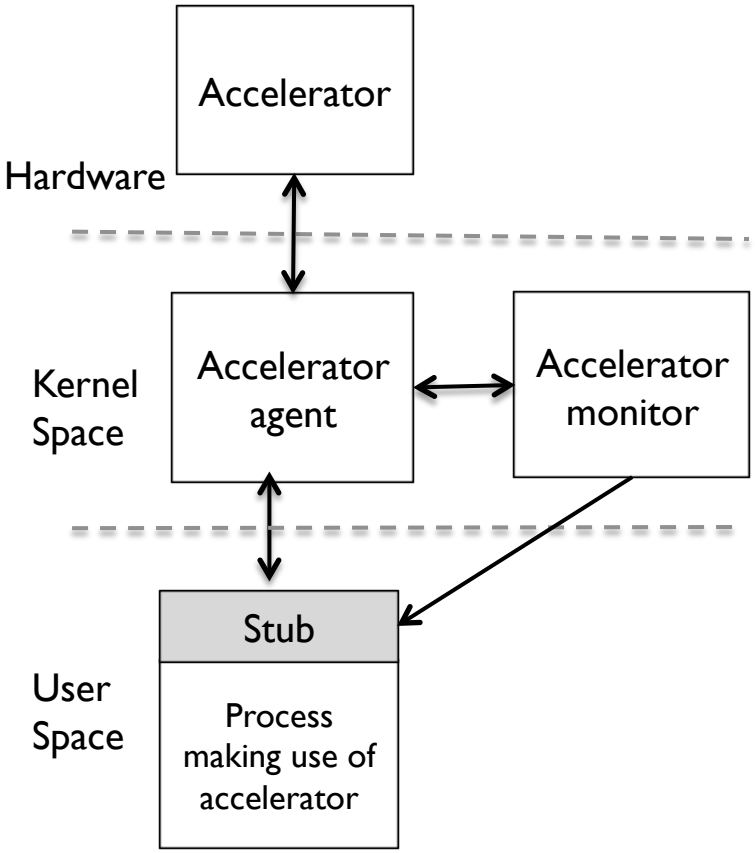


Accelerator agent



- Manages an accelerator
- Roles of an agent
  - Virtualize accelerator
  - Forwarding requests to the accelerator
  - Implement scheduling decisions
  - Expose accounting information to the OS

Accelerator monitor



- Monitors information like utilization of resources
- Responsible for system-wide energy and performance goals
- Acts as an online modeling tool
  - Helps in deciding where to schedule the task

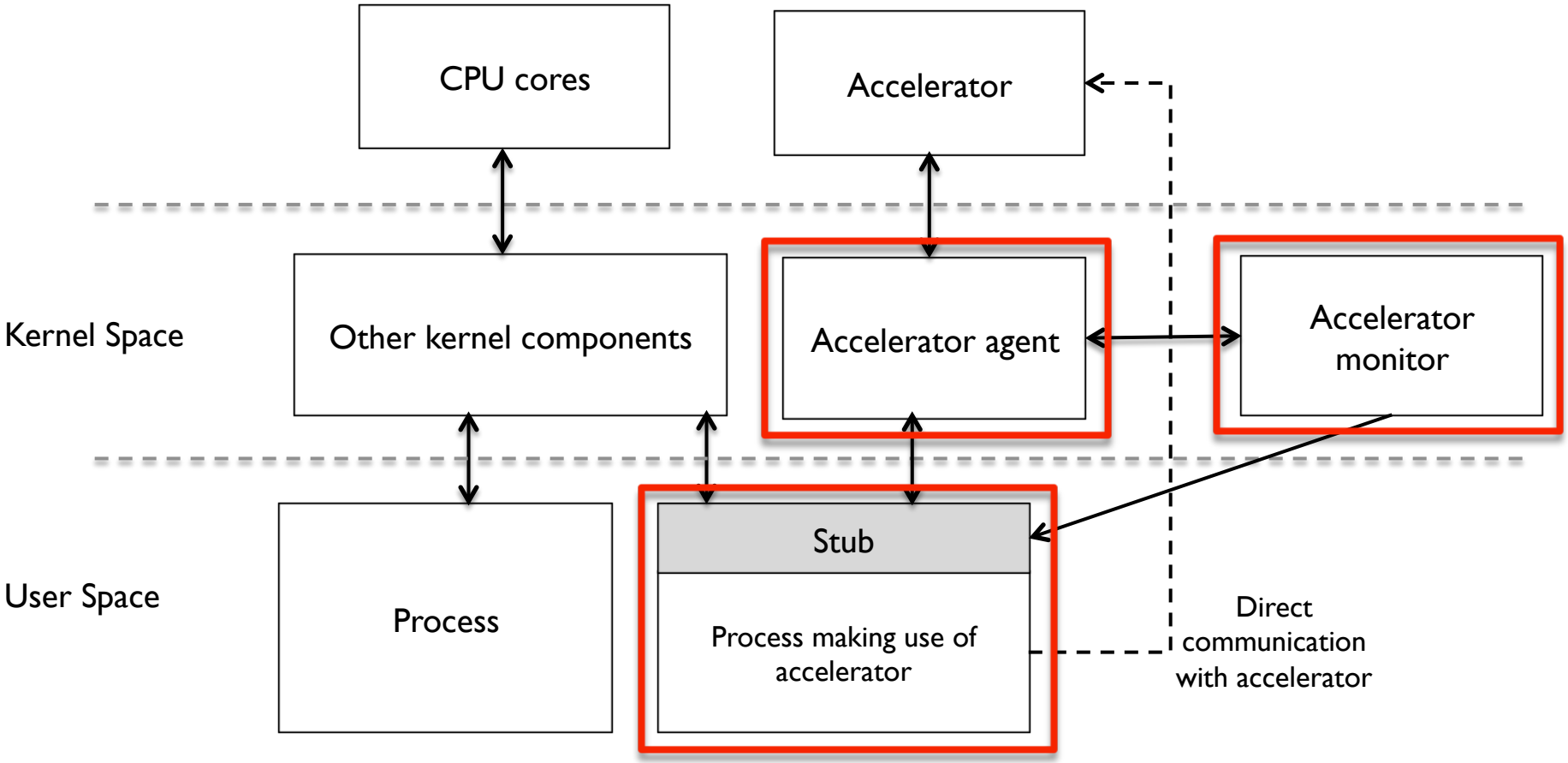
Programming model

- Based on task level parallelism
- Task creation and execution
  - **Write**: different implementations
  - **Launch**: similar to function invocation
  - **Fetching result**: supporting synchronous/asynchronous invocation
- Example: Intel TBB/Cilk

```
application()
{
    task = cryptStub(inputData,
outputData);
    ...
    waitFor(task);
}

<TaskHandle> cryptStub(input,
output)
{
    if(factor1 == true)
      output = implmn_AES(input)
             //or//
    else if(factor2 == true)
      output = implmn_CACC(input)
}
```

Summary


CPU cores
Accelerator
Kernel Space
Other kernel components
Accelerator agent
Accelerator monitor
User Space
Process
Stub
Process making use of accelerator
Direct communication with accelerator

Related work

- Task invocation based on data granularity
  - Merge, Harmony
- Generating device specific implementation of same task
  - GPUOcelot
- Resource scheduling: Sharing between multiple applications
  - PTask, Pegasus

Conclusions

- Accelerators common in future systems
- Rinnegan embraces accelerators through stub mechanism, agent and monitoring components

- Other challenges
  - Data movement between devices
  - Power measurement

Thank You