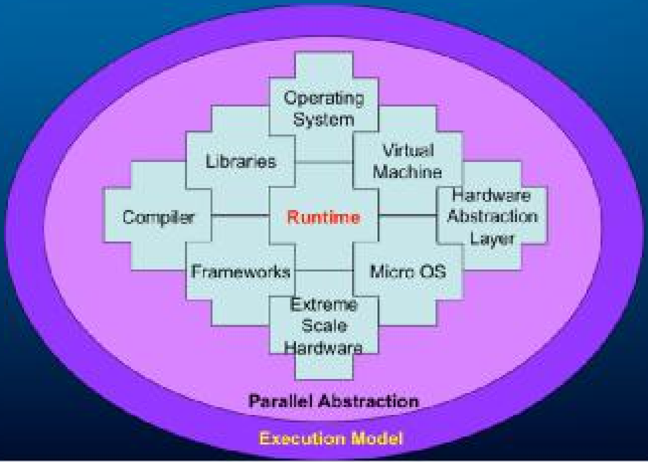
Building an Open Community Runtime (OCR) framework for Exascale Systems

Birds of a Feather Session, SC12, Salt Lake City

November 14, 2012

Organizers: Vivek Sarkar, Barbara Chapman, William Gropp, Rob Knauerhase



Open Community Runtime

Agenda

1. OCR Goals and Approach (10 minutes)
   - Vivek Sarkar
2. Lightning Talks (5 minutes each)
   - Barbara Chapman
   - Bill Gropp
   - Rich Lethin
3. Overview of OCR v0.7 open source release (10 minutes)
   - Rob Knauerhase
4. Hands-on demo of OCR v0.7 release (10 minutes)
   - Romain Cledat
5. Discussion and wrap-up
   - All

Runtime Challenges for Exascale and Extreme Scale Computing

- Performance of extreme scale systems will be driven by parallelism, and constrained by programmability, energy, data movement, and resilience

- Past approaches to parallel runtime systems focused on innovation in isolated layers that focused on isolated resources e.g., communication runtimes for network resources, task-scheduling runtimes for compute resources

è a cooperative (rather than isolated) approach must be pursued to address key challenges in management of shared resources in extreme scale runtime systems

Motivation for an Open Community Runtime

- A runtime framework that …
  - is representative of execution models expected in future extreme scale systems
  - can be targeted by multiple high-level programming systems
  - can be effectively mapped on to multiple extreme scale platforms
  - can be extended and customized for specific programming and platform needs
  - can be used to obtain early results to validate new ideas
  - is available as an open-source testbed

- Approach:
  - Address revolutionary challenges collaboratively
  - Reduce duplication of infrastructure effort, while

Summary of OCR Open Source Project

- Hosted on 01.org (details to follow)
- Goals
  - Modularity
  - Stable APIs
  - Extreme flexibility in implementation
  - Transparency
- Development process
  - Continuous integration
  - Quarterly milestones
  - Mailing lists for technical discussions, build status, etc
- Organization
  - Steering Committee (SC) --- sets overall strategic directions and technical plans
  - Core Team (CT) --- executes technical plan and decides actions to take for source code contributions
  - Membership of SC and CT will turn over periodically based on level of participation

Inaugural Membership for OCR Steering Committee and Core Team

Steering Committee

- Vivek Sarkar (Rice U.)
  - Inaugural Chair
- Barbara Chapman (UH)
- Guang Gao (UD)
- Bill Gropp (UIUC)
- Rob Knauerhase (Intel)
- Rich Lethin (Reservoir)

Core Team

- Zoran Budimlic (Rice)
- Vincent Cave (Rice)
- Sanjay Chatterjee (Rice)
- Romain Cledat (Intel)
- Sagnak Tasirlar (Rice)

OCR Acknowledgments

- Design strongly influenced by
  - Intel Runnemede project (via DARPA UHPC program)
    - power efficiency, programmability, reliability, performance
  - Codelet philosophy – Prof. Gao's group at U. Delaware
    - implicit notions of dataflow
  - Habanero project – Prof. Sarkar's group at Rice U.
    - data-driven tasks, data-driven futures, hierarchical places
  - Concurrent Collections model – Intel Software/Solutions Group
    - decomposition of algorithm into steps/items/tags, tuning
  - Observation-based Scheduling – Intel Labs
    - monitoring and dynamic adaptation to load and environment
  - Machine Description – Prov. Sandrieser, University of Vienna
- *Partial support for the OCR v0.7 release was provided through the X-Stack program funded by U.S. Department of Energy, Office of Science, Advanced Scientific Computing Research (ASCR)*

OCR Assumptions

- A *fine-grained, asynchronous event-driven* runtime framework with *movable data blocks* and *sophisticated observation* enables the next wave of high-performance computing

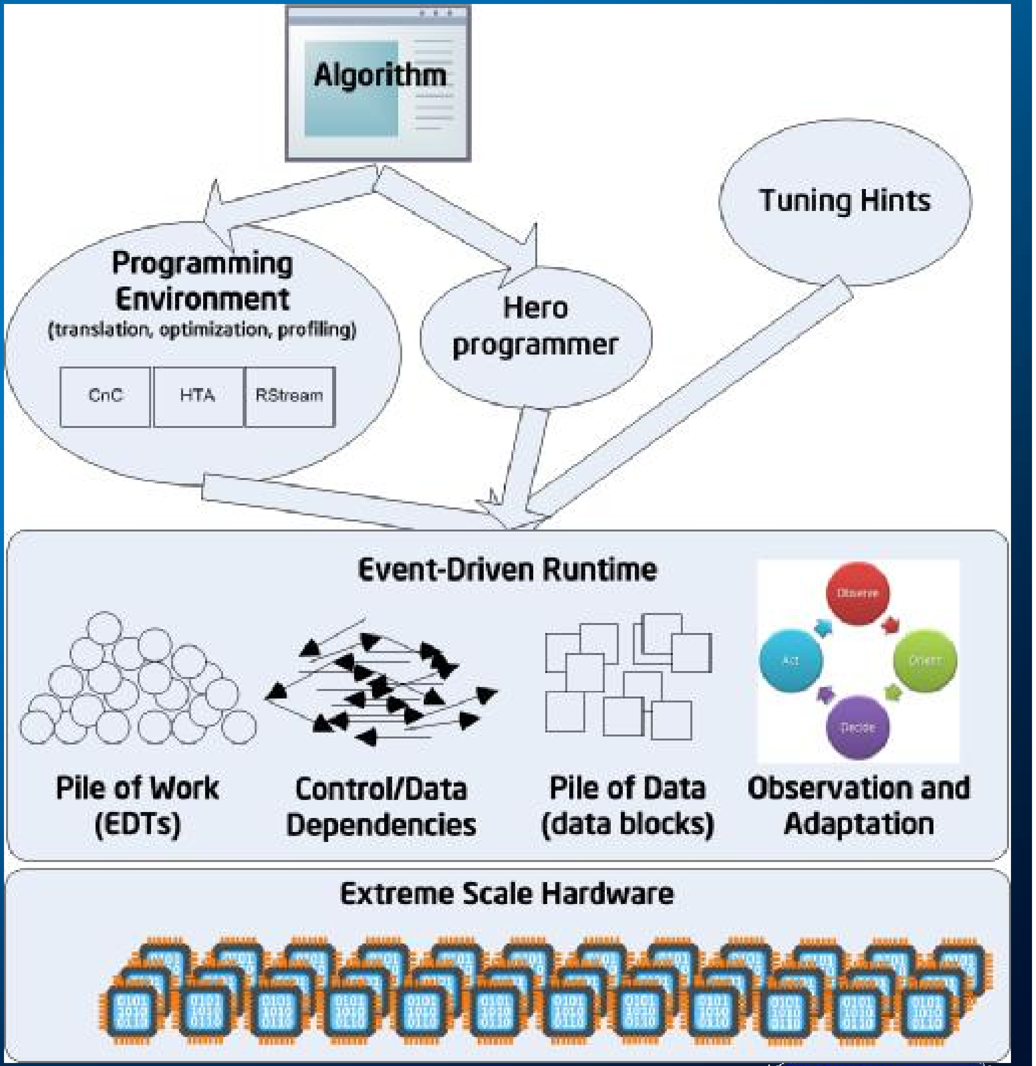
- *Fine-grained parallelism* helps achieve concurrency levels required for extreme scale

- *Asynchronous events* and *movable data blocks* help cope with data movement, non-uniformity, heterogeneity, and resilience in extreme scale applications and platforms

- *Sophisticated observation* enables introspection into system behavior, feedback to OCR client, and adaptation based on algorithmic and performance tuning

OCR High-level Design

- Application/algorithm decomposition exposes greater parallelism than current thread/barrier models
- Separation of concerns among programming environment, hero programmer, tuning hints
- Event-Driven Runtime manages tasks and data blocks to adapt to changes in platform behavior (resilience, machine configuration changes, mission/goal changes), while obeying all control and data dependences



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Open Community Runtime

Thoughts on an Open Runtime

William Gropp

www.cs.illinois.edu/~wgropp

Hybrid Programming and Shared Resources

- Hybrid model is a good thing
- But resources are shared:
  - ♦ Network
  - ♦ Memory bandwidth
  - ♦ Compute cores
  - ♦ Etc.
- How can we make the elements of the hybrid model work together?

Which programming runtime controls resources?

- Currently, most assume that all resources are dedicated to themselves
  - E.g., MPI runtime assumes all cores are used by MPI; OpenMP assumes cores available for OpenMP.
- Allocation of resources is not static
  - E.g., MPI sometimes needs an "agent" for communication progress, esp for nonblocking collective, passive-target RMA, Redezvous point-to-point progress; helpful to take a core for this
- Solution to date: tell programming runtimes at startup what resources they have (if you are lucky)
- Needed: Ways for multiple runtimes to negotiate the resources to share, at startup and during execution
  - Note: Not a common runtime that they all use

Common Capabilities

- Much desire with a common runtime on top of which all parallel programming methods may be implemented
  - ♦ Obvious advantages – shared code, more rapid development
- Unfortunately, not realistic
  - ♦ Programmer productivity can be related (in part) to reducing the size of basic element that can be used and still get good performance (everyone wants this to be a single word)
  - ♦ Performance at this end is extremely sensitive to exact semantics of hardware, implementation (library) overhead, including even length of call list and data alignment

What Can We Do?

- **Alternative: Provide common capabilities for cases that are *not* sensitive to these issues (typically operations involving larger blocks of data)**
  - ♦ **Need to be extensible so that customized interfaces and implementations can be used for the performance critical**
- **Implications**
  - ♦ **Common runtime can provide some services but critical ones will need to designed for and implemented to specific platforms**
    - ***This* work can be shared inside a community, mostly as code examples**
  - ♦ **Runtime must be extensible, with ability to plug in specialized services**

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OpenMP Language and Implementation Technologies Need a Powerful Runtime

Barbara Chapman

University of Houston

OCR BOF, SC12

Acknowledgements: NSF CNS-0833201, CCF-0917285;
DOE DE-FC02-06ER25759

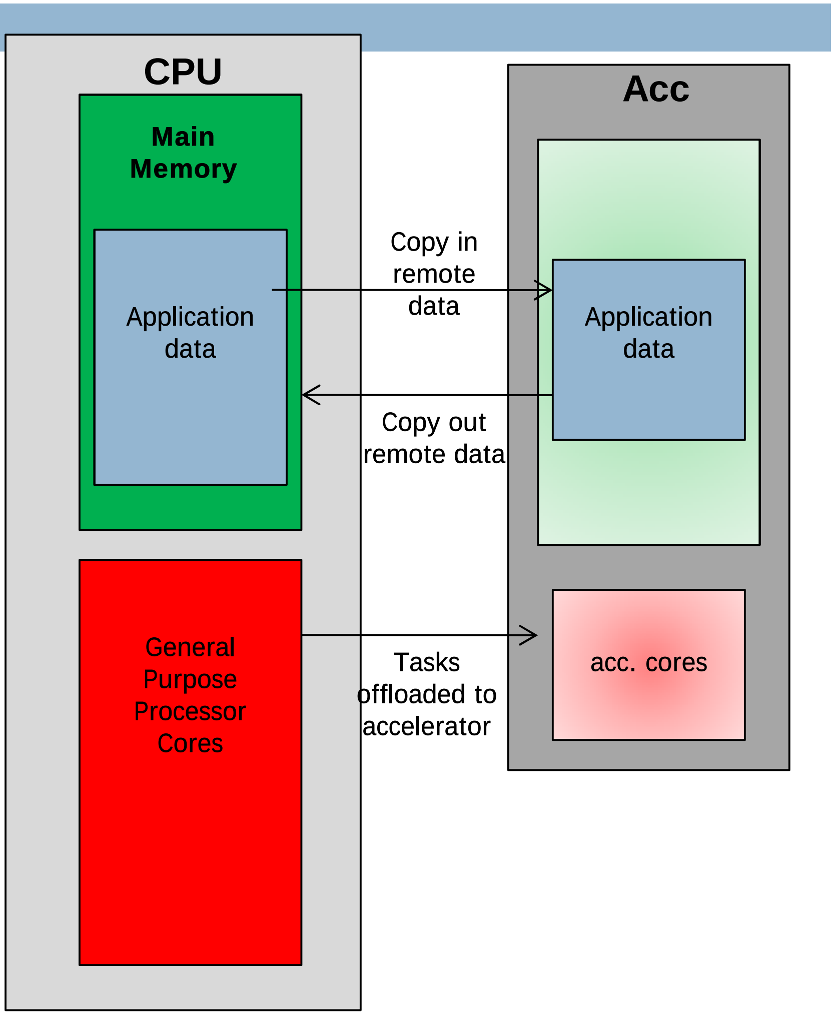
http://www.cs.uh.edu/~hpctools

OpenMP 4.0 Release Candidate 1

- Presented at OpenMP BOF (yesterday)
  - Now on OpenMP website
- Candidate topics:
  - *Affinity and locality*
  - *SIMD extensions*
  - *Error model*
- On-going work:
  - *Accelerator*
  - *Tools interface*

The Accelerator Model

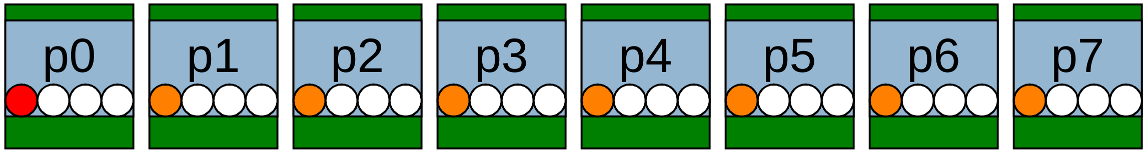
- Execution Model: Offload data and code to accelerator
  - Target construct creates tasks to be executed by devices
  - Initial device thread waits to execute the device tasks
- Memory Model:
  - Data may be copied in or out, allocated on accelerator
  - Copies of shared data are synchronized explicitly or implicitly at end of the target construct regions.
- Integration with tasking extensions
- See technical report



OpenMP 4.0 Affinity Proposal

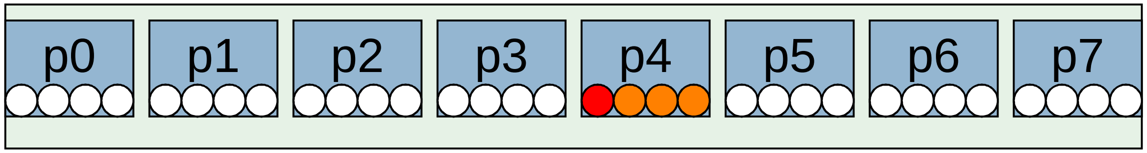
- OpenMP Places and thread affinity policies
  - **OMP_PLACES** to describe places
  - **affinity(spread|compact|true|false)**
- **SPREAD**: spread threads evenly among the places

spread 8



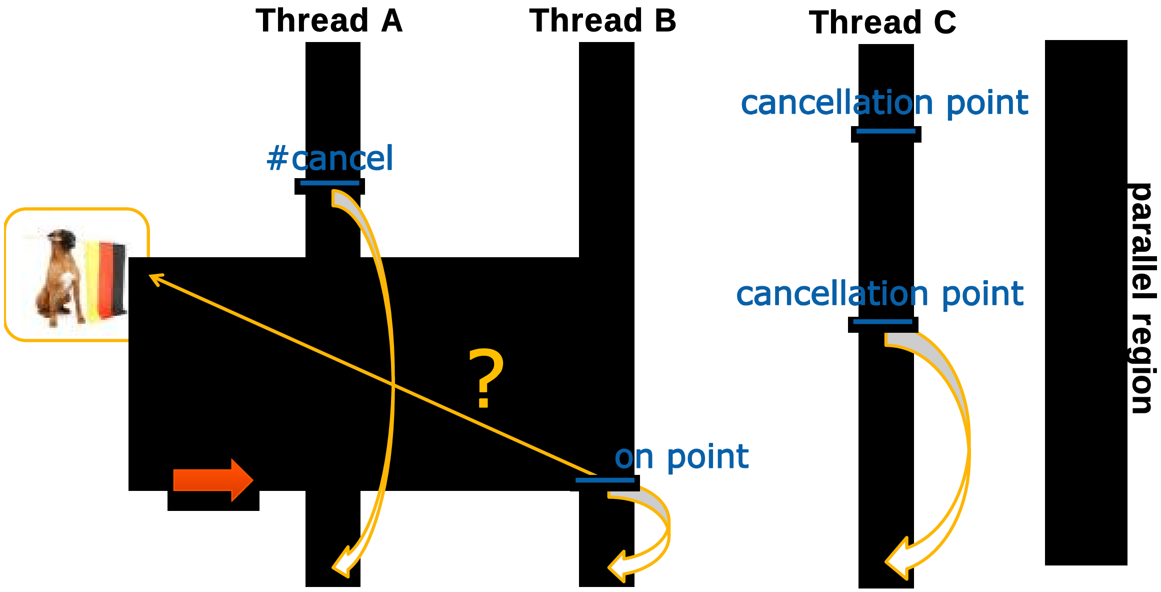
- **COMPACT**: collocate OpenMP thread with master thread

compact 4



OpenMP Error Model

- **Cancel directive**
  - **#pragma omp cancel *[clause[[,]clause] …]***
  - **!$omp cancel *[clause[[,]clause] …]***
  - **Clauses: parallel, sections, for, do**



Toward Asynchronous OpenMP Execution

- May be difficult for user to express computations in form of task graph
- Compiler translates “standard” OpenMP into collection of work units (tasks) and task graph
- Analyzes data usage per work unit
- Trade-off between load balance and co-mapping of work units that use same data
- What is “right” size of work unit?
  - Might need to be adjusted at run time

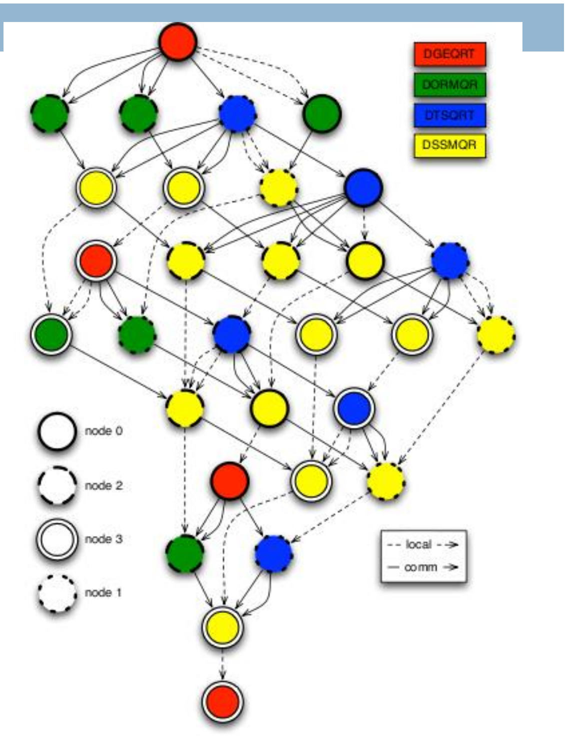
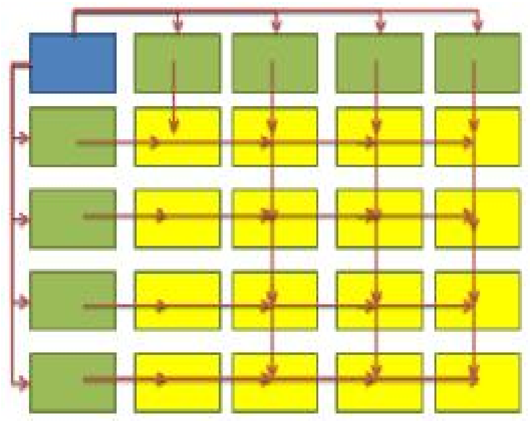


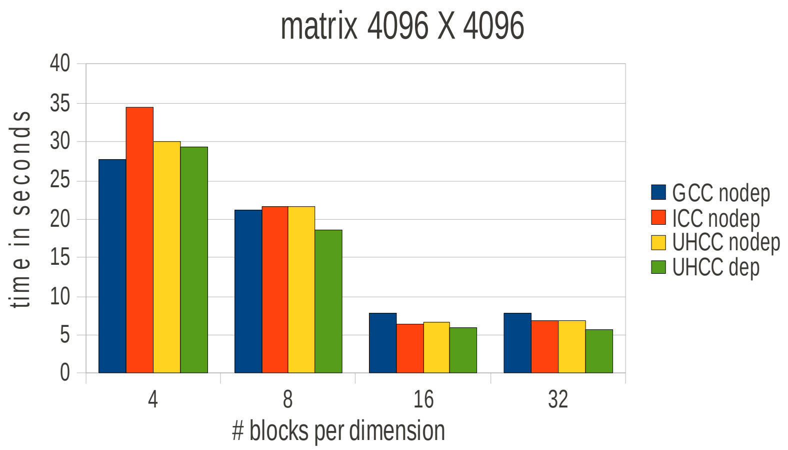
Fig. 5. DAG of QR for a 4x4 tile matrix.

T.-H. Weng, B. Chapman: Implementing OpenMP Using Dataflow Execution Model for Data Locality and Efficient Parallel Execution. Proc. HIPS-7, 2002

Data-Driven Model with OpenMP Tasking Extensions at UH

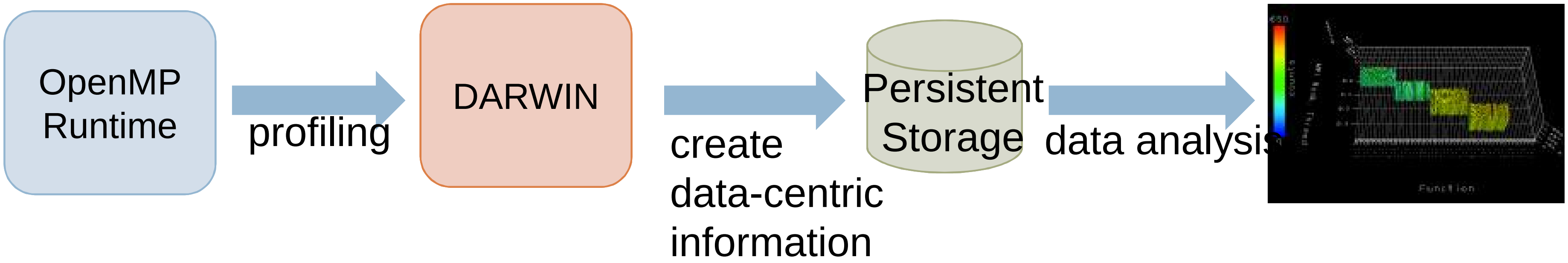
- 1) ***#pragma omp task out [(data – reference – list)]***
- 2) ***#pragma omp task in [(data – reference – list)]***
- Items listed in the data reference list can be thought of as synchronization identifiers called ‘task tags’
- Extensions proposed follow a topological sort
  - a task can only depend on a task which is before it in program order





DARWIN: Feedback-Based Adaptation

- Dynamic Adaptive Runtime Infrastructure
  - Online and offline (compiler or tool) scenarios
  - Monitoring
    - Capture performance data for analysis via monitoring
    - Relate data to source code and data structures
    - Apply optimization and / or visualize
    - Demonstrated ability to optimize page placement on NUMA platform; results independent of numthreads, data size


OpenMP Runtime

profiling

DARWIN

create data-centric information

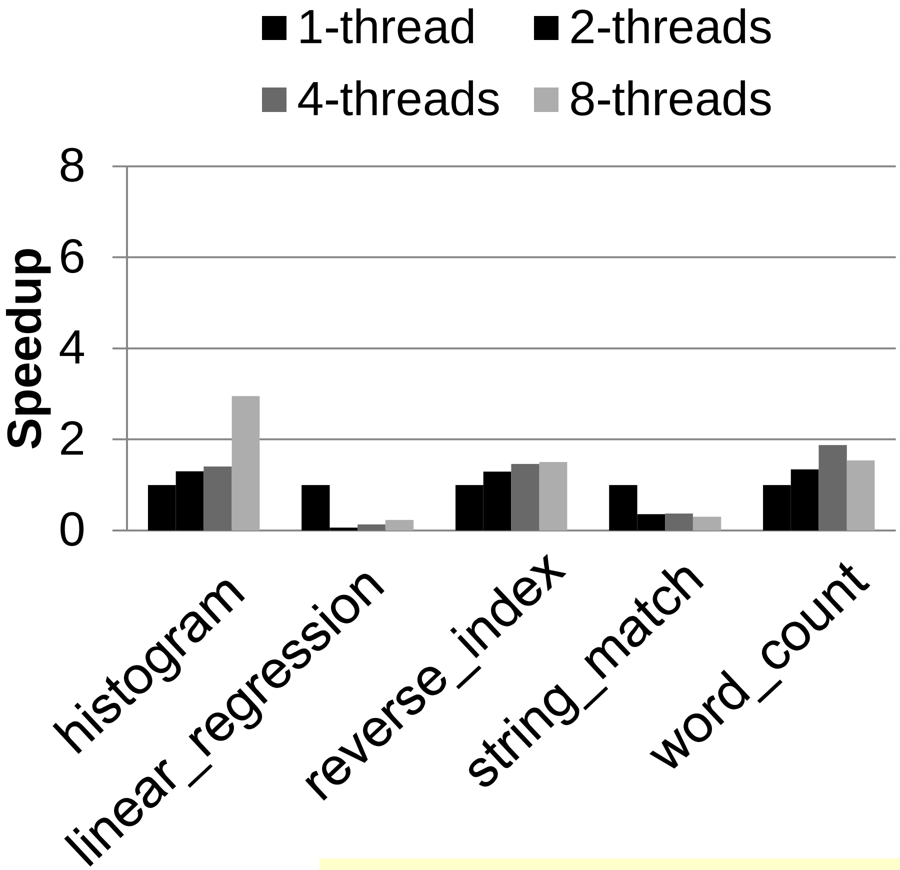
Persistent Storage

data analysis

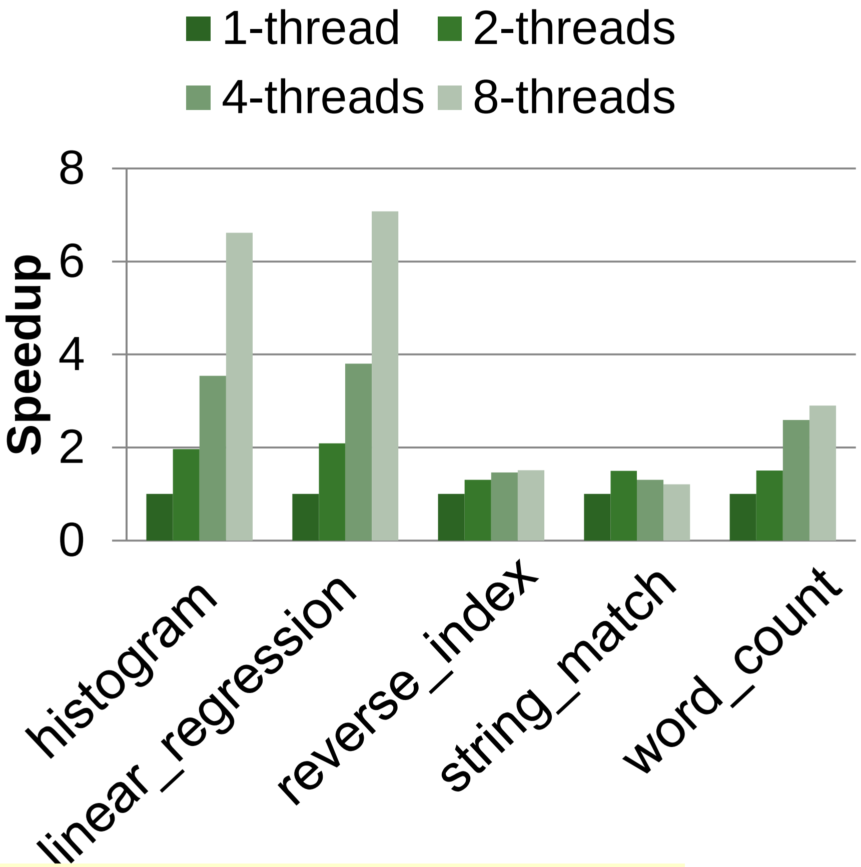
Besar Wicaksono, Ramachandra C Nanjegowda, and Barbara Chapman. A Dynamic Optimization Framework for OpenMP. IWOMP 2011

Runtime False Sharing Detection

Original Version



Optimized Version



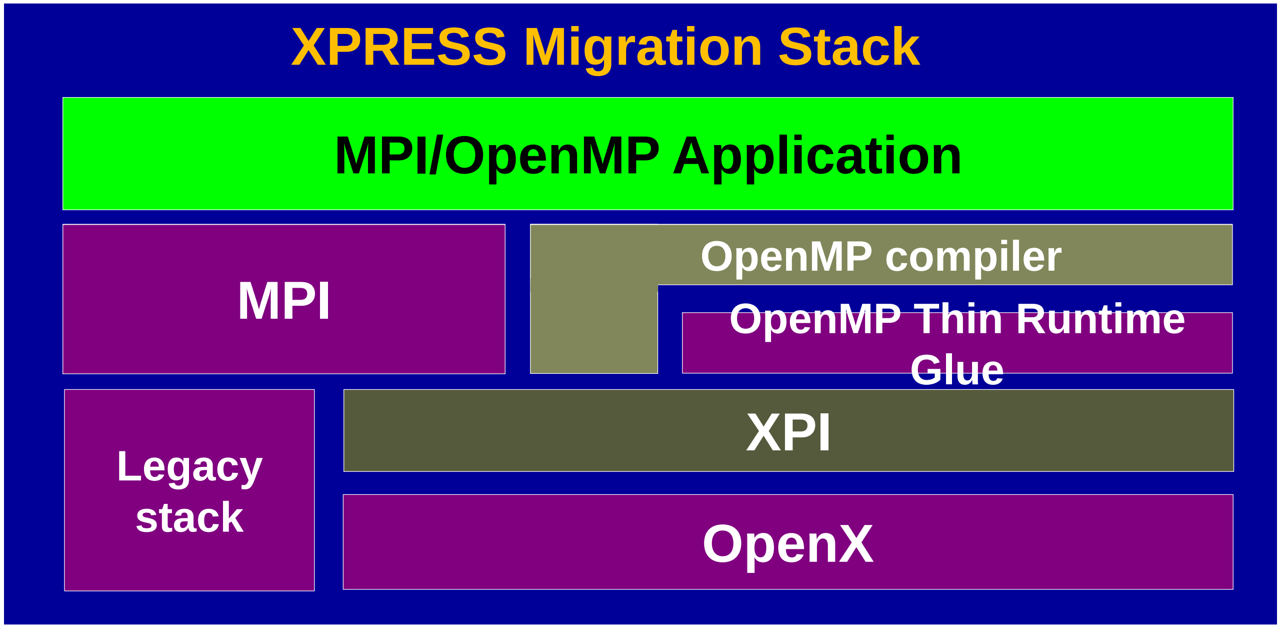
B. Wicaksono, M. Tolubaeva and B. Chapman. "Detecting false sharing in OpenMP applications using the DARWIN framework", LCPC 2011

OCR Support for Legacy Applications

- OCR needs to be able to support current and future programming model
  - Very important to support legacy apps
  - Opens up to a wide range of apps
  - Novel implementation techniques for existing models
  - Explore new features, limitations, new programming models

Goals for Legacy Code Migration

- Support legacy MPI and OpenMP codes in XPRESS
- Develop a migration path for OpenMP and MPI application toward new execution model
- Communicate XPRESS experiences back to standards committee
  - Potentially suggest extensions to OpenMP and MPI with features from XPRESS



The end

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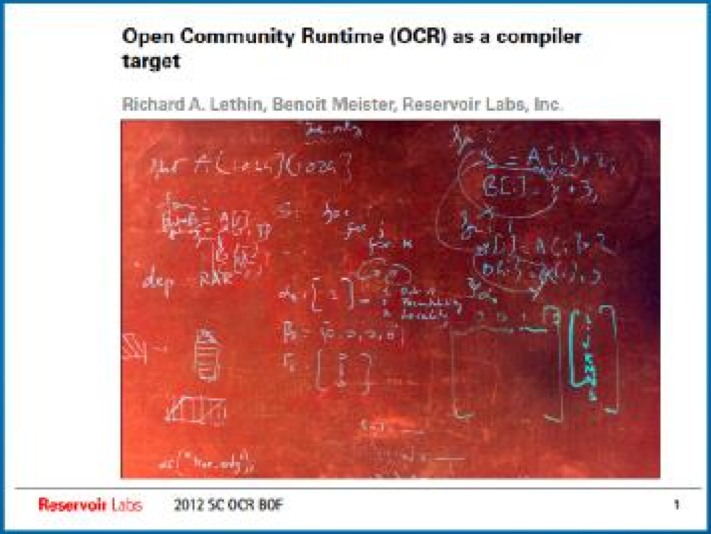
Reservoir presentation

- (See embedded PDF – after SC12, we'll post all the slides in the same format. **J**)



Open Community Runtime (OCR) as a compiler target

Richard A. Lethin, Benoit Meister, Reservoir Labs, Inc.

Reservoir Labs 2012 SC OCR BOF 1

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What's *not* in OCR v0.7

- It's scaffolding,
  - just a framework

- It's *not the Sears Tower!* *(yet)*

What’s in OCR v0.7

- Event-driven tasks (EDTs)

  inc/ocr-edt.h

  - can be processes, functions or codelets (open research question)
    - decomposition is up to programmer & compiler
  - could be data-parallel within themselves

- Events (Dependences)

  inc/ocr-edt.h

  - specified explicitly as contingencies on which EDTs are initiated
    - EDTs can fire anytime after all their dependences are met
  - several types of dependences
    - control dependences: B cannot start until A finishes
    - data dependences: B cannot start until inputs D1 and D2 are available, and processing on D3 has finished
    - independent events (e.g. triggers, environment, …)
  - dependences are specified as GUIDs throughout the system

Open Community Runtime

What’s in OCR v0.7

inc/ocr-db.h

- Memory datablocks
  - replacement for malloc()
  - contains semantically-meaningful metadata that runtime can use
  - relocatable by runtime for power, reliability, …
    - exploring hardware assistance; no movement in v0.7 release
  - allows exploitation (or modeling) of NUMA, scratchpad memories, etc.
    - e.g. instrumentation to infer energy usage from different placements and configurations

xsd/ocr-pdl.xsd

- Machine description
  - XML schema plus conforming XML documents
    - based largely on U. Vienna’s Platform Description Language
  - allows expression of hw configuration (cores, memory, interconnect)
    - exploration of same decompositions on different hardware, real or simulated
  - current state: present, but barebones, not fully used

Implementation Details

- Complete but *non-optimized* implementation
  - performance is not (yet!) a goal
- Runs on top of Linux
  - shows functionality without having to build a whole OS
  - other versions running on simulation (UHPC, X-stack)
- Supports “hero programmers” for nontrivial apps
  - pending programming model integrations
- Modularity as a goal whenever possible
  - for ease of subsystem replacement, augmentation, …
  - supporting other research using OCR components

What’s coming in OCR v(0.7++)

- Distribution
  - runtime functionality across “nodes” w/separate memory spaces
    - MPI integration under the covers
- Tuning expression
  - hints via better groupings for temporospatial locality
    - leverage hierarchical place trees and CnC affinity groups, …
- Machine description improvements
  - better integration with runtime
  - ongoing observation of machine state (load, failures, …)
- Different underlying thread support
  - e.g. Sandia Qthreads, direct mapping to hw threads

OCR resources

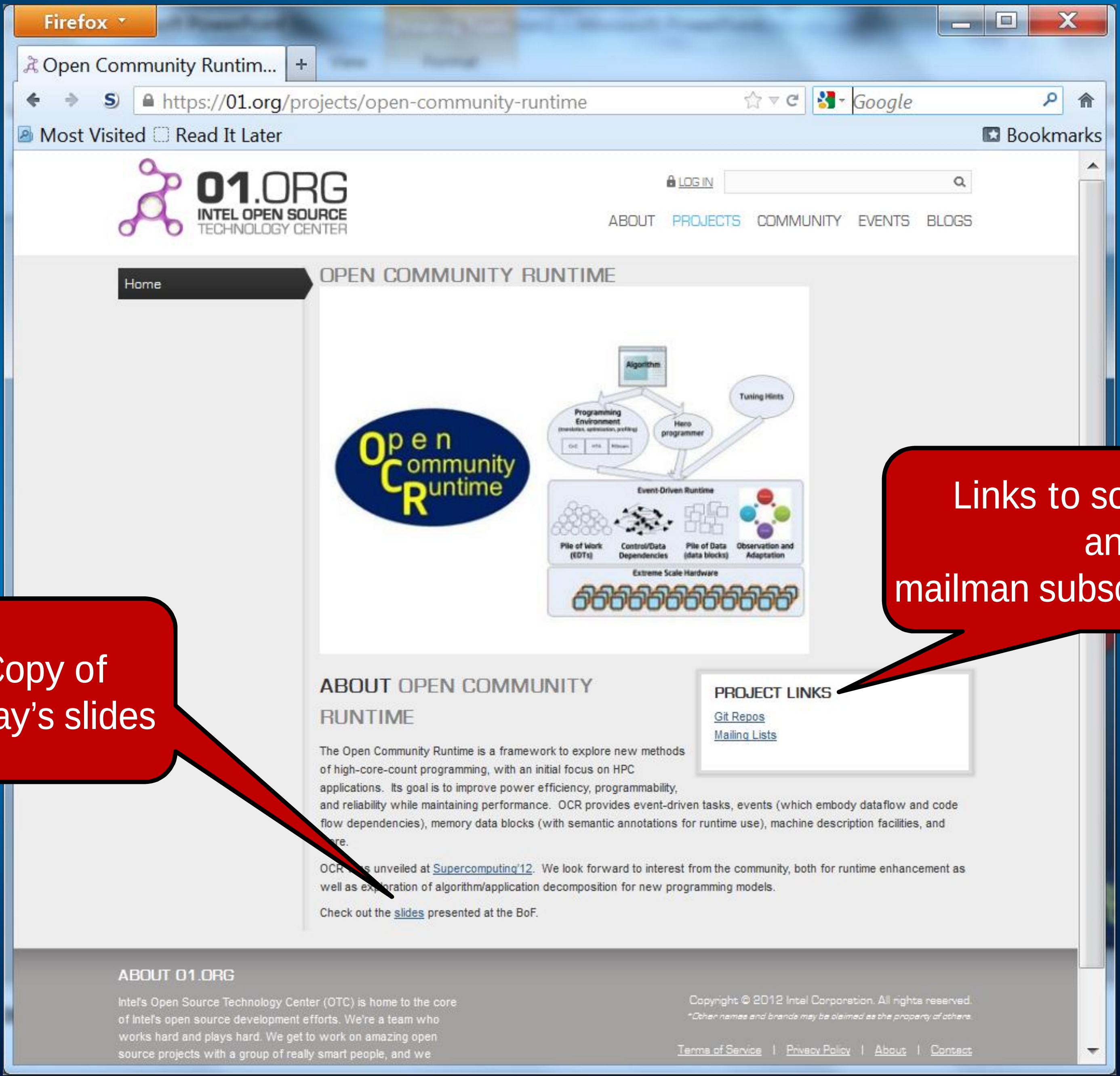
- Project homepage at **http://01.org/projects/open-community-runtime**
- Public repository on github **http://github.com/01org/ocr**
- Mailing lists
  - ocr-announce
  - ocr-devel
  - ocr-discuss
  - ocr-build
- Wiki and so forth coming soon

graciously hosted by

INTEL OPEN SOURCE
TECHNOLOGY CENTER

http://01.org/projects/
open-community-runtime

Open
Community
Runtime



OPEN COMMUNITY RUNTIME

ABOUT OPEN COMMUNITY RUNTIME

The Open Community Runtime is a framework to explore new methods of high-core-count programming, with an initial focus on HPC applications. Its goal is to improve power efficiency, programmability, and reliability while maintaining performance. OCR provides event-driven tasks, events (which embody dataflow and code flow dependencies), memory data blocks (with semantic annotations for runtime use), machine description facilities, and more.

OCR was unveiled at Supercomputing'12. We look forward to interest from the community, both for runtime enhancement as well as exploration of algorithm/application decomposition for new programming models.

Check out the slides presented at the BoF.

PROJECT LINKS

Git Repos

Mailing Lists

ABOUT 01.ORG

Intel's Open Source Technology Center (OTC) is home to the core of Intel's open source development efforts. We're a team who works hard and plays hard. We get to work on amazing open source projects with a group of really smart people, and we

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Copy of
today's slides

How you can get involved

- Runtime development
  - soliciting code contributions; we can use more brains/hands!
  - build a new subsystem, or adapt OCR to your existing research
- Develop/port applications
  - by-hand or compiler-driven decomposition into EDTs
  - explore behavior of different types of algorithms and tunings
  - enable execution on different machine types (including research architectures)
- Join the discussion mailing list
  - offer input about connections to other work, insight into areas in which you have expertise/experience

Live demonstration

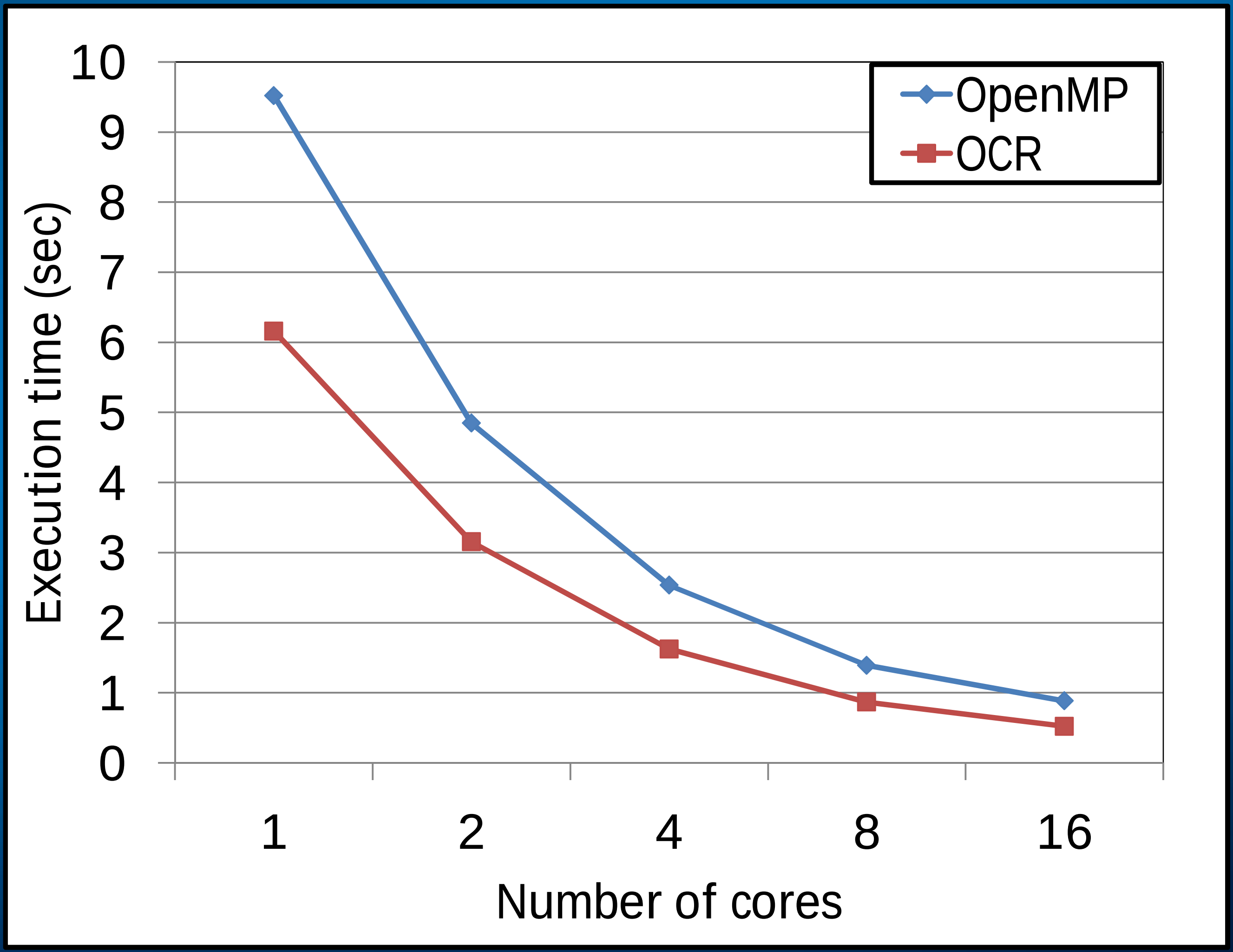
Smith-Waterman implementation

```
ocrEdtCreate(&task_guid, smith_waterman_task, 9, NULL,
             (void**) p_paramv, PROPERTIES, 3, NULL);

ocrAddDependency(tile_matrix[i][j-1].right_column_event_guid,
                 task_guid, 0);
ocrAddDependency(tile_matrix[i-1][j].bottom_row_event_guid,
                 task_guid, 1);
ocrAddDependency(tile_matrix[i-1][j1].bottom_right_event_guid,
                 task_guid, 2);

ocrEdtSchedule(task_guid);
```

OCR Comparison with OpenMP
(Smith-Waterman algorithm)



Input set of ~37k nucleotides

(see http://en.wikipedia.org/wiki/Smith-Waterman_algorithm)

Questions?

Comments?

Unbridled enthusiasm?

(If you did not receive a flyer with information and the API cheat sheet, please pick one up on the way out!)

Open Community Runtime