Fast, Reliable, Loosely Coupled Parallel Computation

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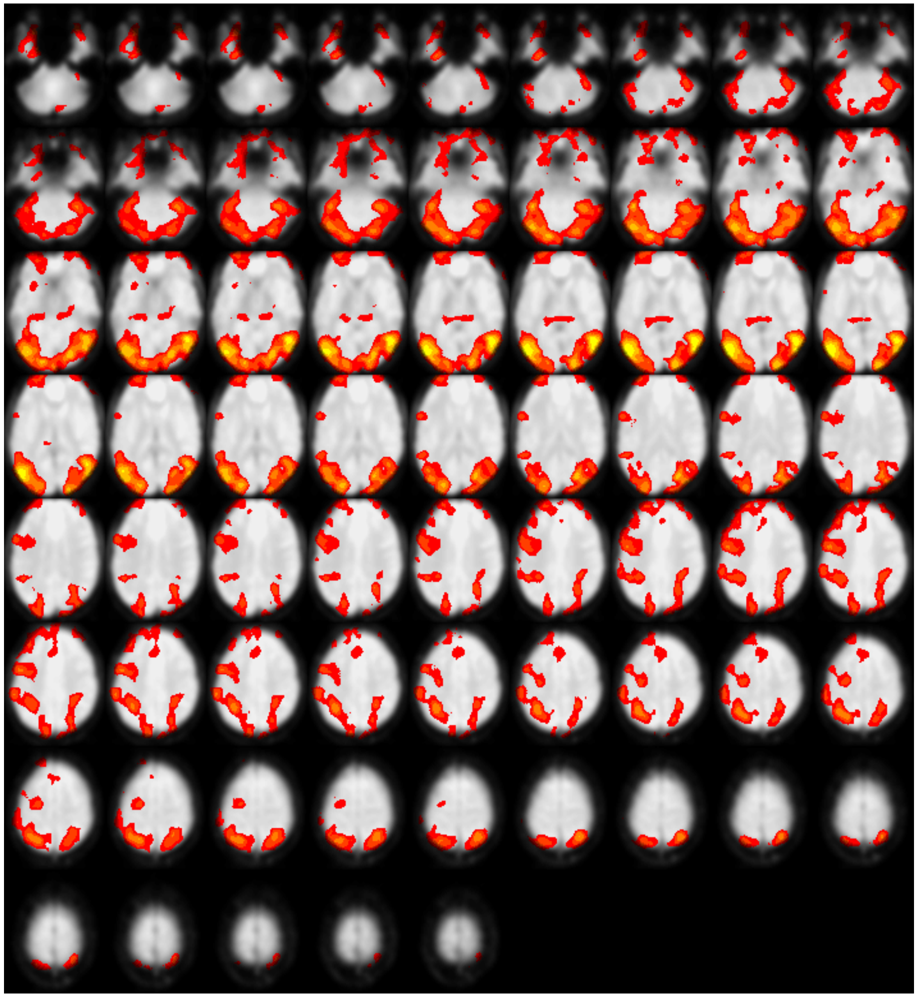
Joint work with **Yong Zhao, Ioan Raicu, Mike Wilde, Ben Clifford, Mihael Hatigan, Tibi Stef-Praun, Veronika Nefedova**

Case Study:
Functional MRI (fMRI) Data Center

- Online repository of neuroimaging data
- A typical study comprises
  - 3 groups,
  - 20 subjects/group,
  - 5 runs/subject,
  - 300 volumes/run

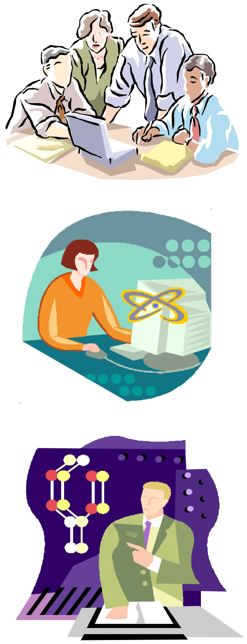
  → 90,000 volumes, 60 GB raw

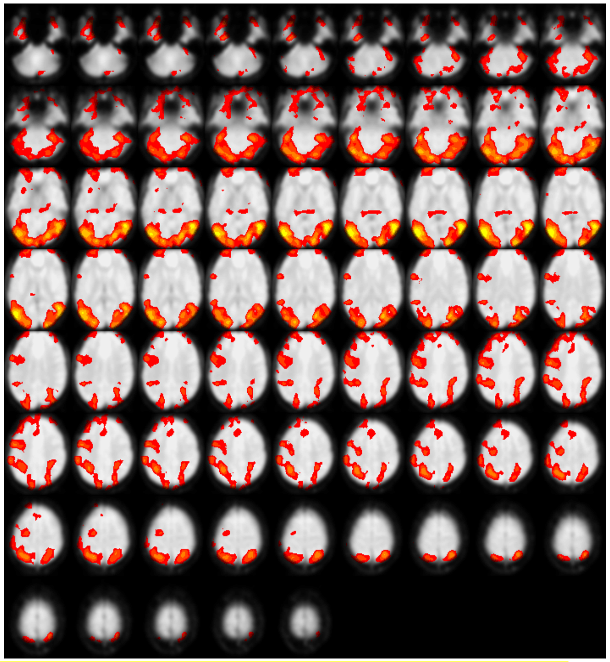
  → 1.2 million files processed
- 100s of such studies in total

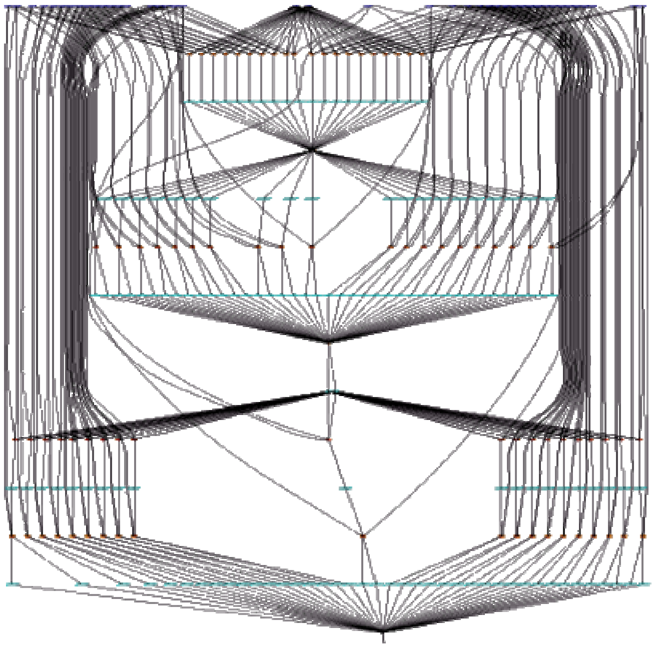


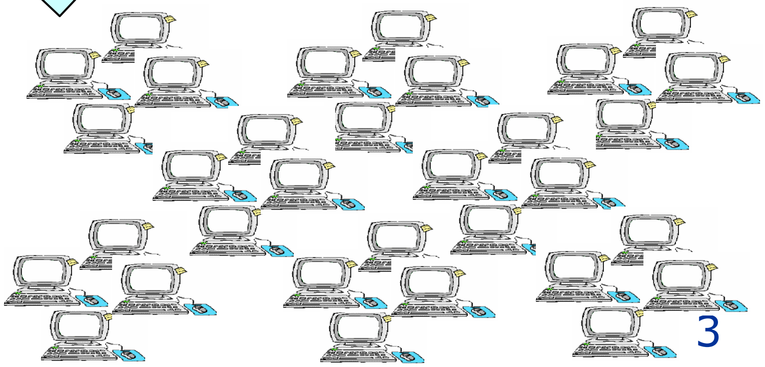
www.fmridc.org

Many Users Analyze fMRI Data









- Wide range of analyses
  - Testing, interactive analysis, production runs
  - Data mining
  - Parameter studies

Three Obstacles to Creating a Community Resource

- Accessing messy data
  - ◆ Idiosyncratic layouts & formats
  - ◆ Data integration a prerequisite to analysis
- Implementing complex computations
  - ◆ Expression, discovery, reuse of analyses
  - ◆ Scaling to large data, complex analyses
- Making analysis a community process
  - ◆ Collaboration on both data & programs
  - ◆ Provenance: tracking, query, application

The **Swift** Solution (Or: Outline of this Talk)

- Accessing messy data
  - Idiosyncratic layouts & formats
  - Data integration a prerequisite to analysis

XDTM

- Implementing complex computations
  - Expression, discovery, reuse of analyses
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SwiftScript

Karajan +Falkon

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VDC

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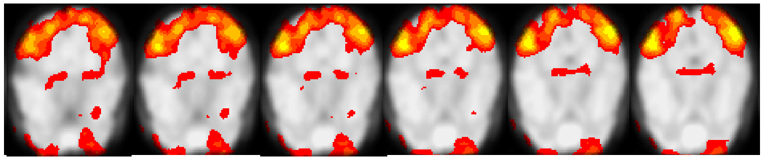
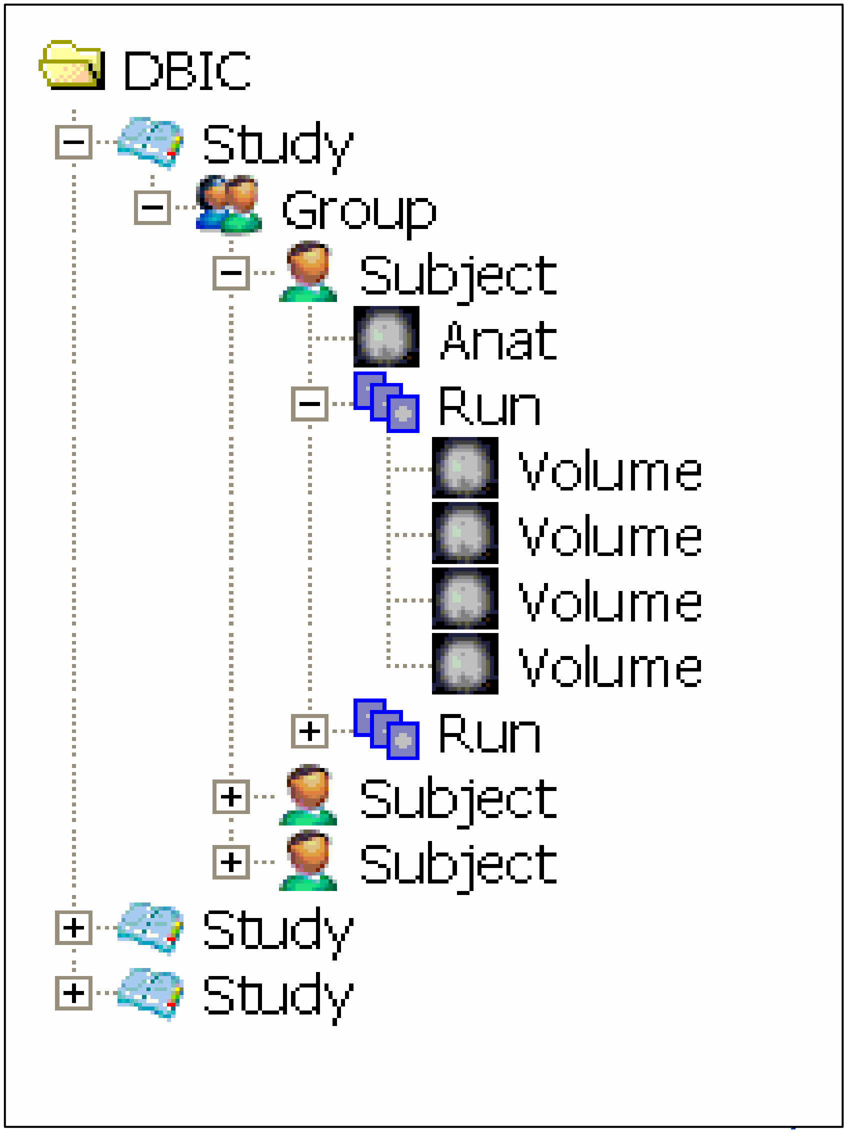
The Messy Data Problem (1)

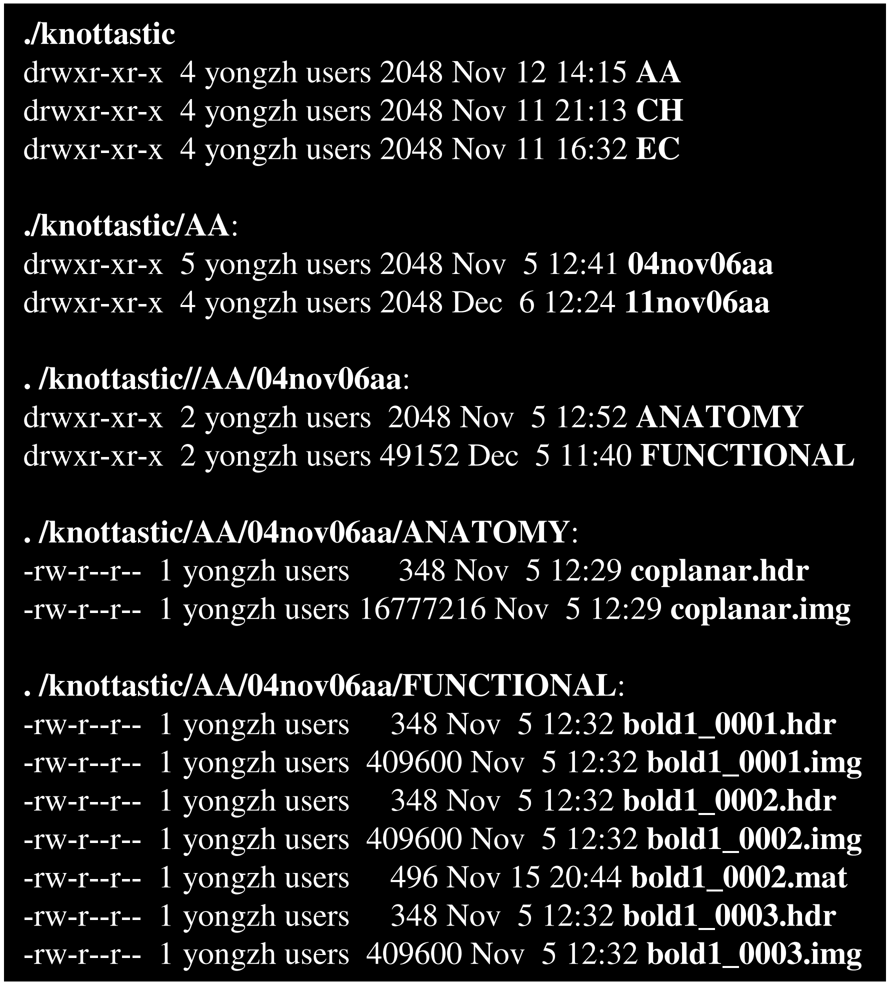
- Scientific data is often logically structured
  - E.g., hierarchical structure
  - Common to map functions over dataset members
  - Nested map operations can scale to millions of objects





The Messy Data Problem (2)

- Heterogeneous storage format & access protocols
  - Same dataset can be stored in text file, spreadsheet, database, …
  - Access via filesystem, DBMS, HTTP, WebDAV, …
- Metadata encoded in directory and file names
- Hinders program development, composition, execution



```
./knottastic
drwxr-xr-x  4 yongzh users 2048 Nov 12 14:15 AA
drwxr-xr-x  4 yongzh users 2048 Nov 11 21:13 CH
drwxr-xr-x  4 yongzh users 2048 Nov 11 16:32 EC

./knottastic/AA:
drwxr-xr-x  5 yongzh users 2048 Nov  5 12:41 04nov06aa
drwxr-xr-x  4 yongzh users 2048 Dec  6 12:24 11nov06aa

. /knottastic//AA/04nov06aa:
drwxr-xr-x  2 yongzh users  2048 Nov  5 12:52 ANATOMY
drwxr-xr-x  2 yongzh users 49152 Dec  5 11:40 FUNCTIONAL

. /knottastic/AA/04nov06aa/ANATOMY:
-rw-r--r--  1 yongzh users      348 Nov  5 12:29 coplanar.hdr
-rw-r--r--  1 yongzh users 16777216 Nov  5 12:29 coplanar.img

. /knottastic/AA/04nov06aa/FUNCTIONAL:
-rw-r--r--  1 yongzh users    348 Nov  5 12:32 bold1_0001.hdr
-rw-r--r--  1 yongzh users  409600 Nov  5 12:32 bold1_0001.img
-rw-r--r--  1 yongzh users    348 Nov  5 12:32 bold1_0002.hdr
-rw-r--r--  1 yongzh users  409600 Nov  5 12:32 bold1_0002.img
-rw-r--r--  1 yongzh users    496 Nov 15 20:44 bold1_0002.mat
-rw-r--r--  1 yongzh users    348 Nov  5 12:32 bold1_0003.hdr
-rw-r--r--  1 yongzh users  409600 Nov  5 12:32 bold1_0003.img
```

➔ XML Dataset Typing & Mapping (XDTM)

- Describe logical structure by **XML Schema**
  - Primitive scalar types: int, float, string, date, …
  - Complex types (structs and arrays)
- Use **mapping descriptors** for mappings
  - How dataset elements are mapped to physical representations
  - External parameters (e. g. location)
- Use **XPath** for dataset selection

XDTM: XML Dataset Typing and Mapping for Specifying Datasets [EGC05]

XDTM: Related Work

- Data format standardization
  - FITS, CDF, HDF-5, DICOM
- Data format description
  - DFDL [Beckerle,Westhead04] embeds annotations with XML Schema
  - PADS [Fisher,Gruber05], PADX [Fernandez,Fisher06], declarative specs of physical layout & semantics
- Logical object
  - ADO [Microsoft01], in-memory relational model
  - SDO [Beatty,Brodsky03], logical data model for J2EE

XDTM: Implementation

- Virtual integration
  - Each data source treated as virtual XML source
  - Data structure defined as XML schema
  - Mapper responsible for accessing source and translating to/from XML representation
  - Bi-directional
- Common mapping interface
  - Data providers implement the interface
    - Responsible for data access details
  - Standard mapper implementations provided
    - String, file system, CSV, …

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Karajan
+Falkon

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VDC

SwiftScript

- Typed parallel programming notation
  - XDTM as data model and type system
  - Typed dataset and procedure definitions
- Scripting language
  - Implicit data parallelism
  - Program composition from procedures
  - Control constructs (foreach, if, while, …)

Clean application logic
Type checking
Dataset selection, iteration
Discovery by types
Type conversion

A Notation & System for Expressing and Executing Cleanly Typed Workflows on Messy Scientific Data [SIGMOD05]

SwiftScript: Related Work

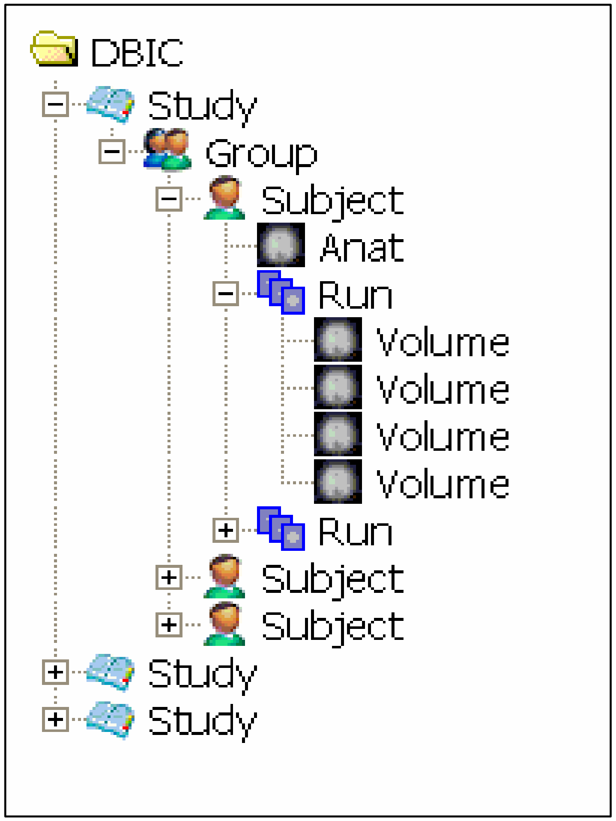
- Coordination language
  - Linda[Ahuja,Carriero86], Strand[Foster,Taylor90], PCN[Foster92]
  - Durra[Barbacci,Wing86], MANIFOLD[Papadopoulos98]
  - Components programmed in specific language (C, FORTRAN) and linked with system
- “Workflow” languages and systems
  - Taverna[Oinn,Addis04], Kepler[Ludäscher,Altintas05], Triana [Churches,Gombas05], Vistrail[Callahan,Freire06], DAGMan, Star-P
  - XPDL[WfMC02], BPEL[Andrews,Curbera03], and BPML[BPML02], YAWL[van de Aalst,Hofstede05], Windows Workflow Foundation [Microsoft05]

Related Work

	SwiftScript	BPEL	XPDL	MW Wflow	DAGMan	Tavena	Triana	Kepler	Vistrail	Star-P
Scales to Grids	++	-	-	-	++	-	-	-	-	+
Typing	++	++	++	++	-	-	-	+	-	+
Iteration	++	-/+	-	+	-	-	-	+	-	+
Scripting	++	-	-	+	+	+	-	-	+	++
Dataset Mapping	+	-	-	-	-	-	-	-	-	-
Service Interop	+	-	+	-	-	-	-	+	-	-
Subflow/comp.	+	-	+	+	-	-	+	+	-	+
Provenance	+	-	-	+	-	+	-	+	+	-
Open source	+	+	+	-	+	+	+	+	+	-

"A 4x200 flow leads to a 5 MB BPEL file … chemists were not able to write in BPEL" [Emmerich,Buchart06]

fMRI Type Definitions in SwiftScript



- DBIC
  - Study
    - Group
      - Subject
        - Anat
        - Run
          - Volume
          - Volume
          - Volume
          - Volume
        - Run
      - Subject
      - Subject
  - Study
  - Study

Simplified version of fMRI AIRSN Program (Spatial Normalization)

```
type Study {
            Group g[ ];
}

type Group {
            Subject s[ ];
}

type Subject {
            Volume anat;
            Run run[ ];
}

type Run {
            Volume v[ ];
}

type Volume {
            Image img;
            Header hdr;
}
```

```
type Image {};

type Header {};

type Warp {};

type Air {};

type AirVec {
            Air a[ ];
}

type NormAnat {
            Volume anat;
            Warp aWarp;
            Volume nHires;
}
```

Type Definitions in XML Schema

```
<xs:schema targetNamespace="http://www.fmri.org/schema/airsn.xsd"
           xmlns="http://www.fmri.org/schema/airsn.xsd"
           xmlns:xs="http://www.w3.org/2001/XMLSchema">
        <xs:simpleType name="Image">
            <xs:restriction base="xs:string"/>
        </xs:simpleType>
        <xs:simpleType name="Header">
            <xs:restriction base="xs:string"/>
        </xs:simpleType>
        <xs:complexType name="Volume">
            <xs:sequence>
                <xs:element name="img" type="Image"/>
                <xs:element name="hdr" type="Header"/>
            </xs:sequence>
        </xs:complexType>
        <xs:complexType name="Run">
            <xs:sequence minOccurs="0” maxOccurs="unbounded">
                <xs:element name="v" type="Volume"/>
             </xs:sequence>
        </xs:complexType>
</xs:schema>
```

fMRI Example:
AIRSN Program Definition

```
(Run snr) functional ( Run r, NormAnat a,
                       Air shrink ) {
    Run yroRun = reorientRun( r , "y" );
    Run roRun = reorientRun( yroRun , "x" );
    Volume std = roRun[0];
    Run rndr = random_select( roRun, 0.1 );
    AirVector rndAirVec = align_linearRun( rndr, std, 12, 1000, 1000, "81 3 3" );
    Run reslicedRndr = resliceRun( rndr, rndAirVec, "o", "k" );
    Volume meanRand = softmean( reslicedRndr, "y", "null" );
    Air mnQAAir = alignlinear( a.nHires, meanRand, 6, 1000, 4, "81 3 3" );
    Warp boldNormWarp = combinewarp( shrink, a.aWarp, mnQAAir );
    Run nr = reslice_warp_run( boldNormWarp, roRun );
    Volume meanAll = strictmean( nr, "y", "null" )
    Volume boldMask = binarize( meanAll, "y" );
    snr = gsmoothRun( nr, boldMask, "6 6 6" );
}
```

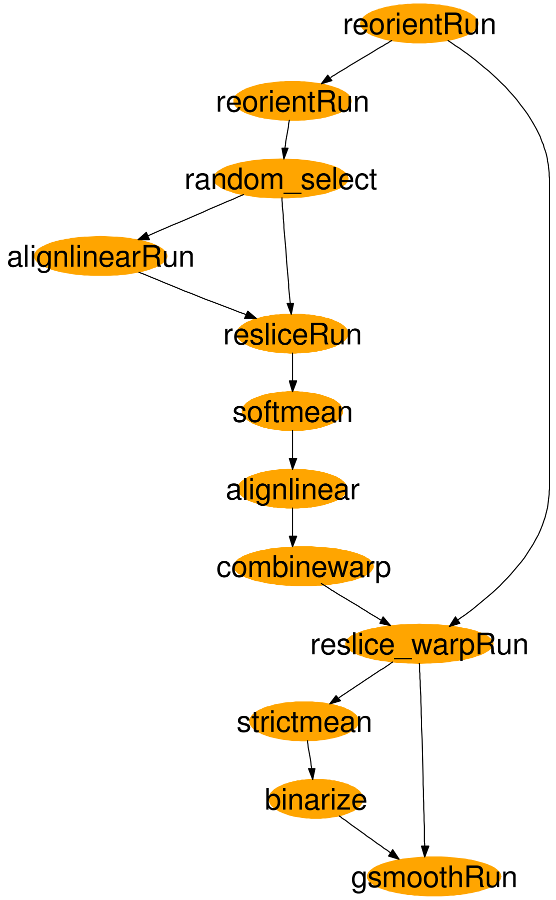
```
(Run or) reorientRun (Run ir,
                      string direction) {
    foreach Volume iv, i in ir.v {
        or.v[i] = reorient(iv, direction);
    }
}
```

Collaboration with James Dobson, Dartmouth [SIGMOD05]

Expressiveness

Lines of code with different encodings

Appln	Script	Generator	Swift Script
ATLAS1	49	72	**6**
ATLAS2	97	135	**10**
FILM1	63	134	**17**
FEAT	84	191	**13**
AIRSN	215	~400	**34**



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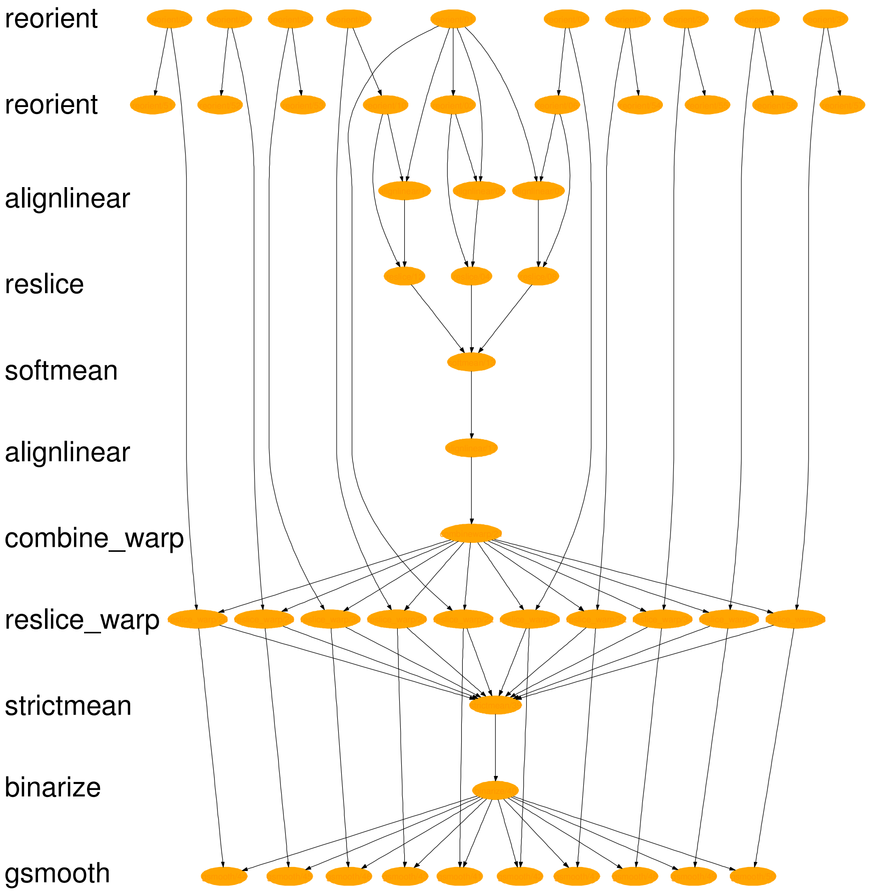

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VDC

Swift Runtime System

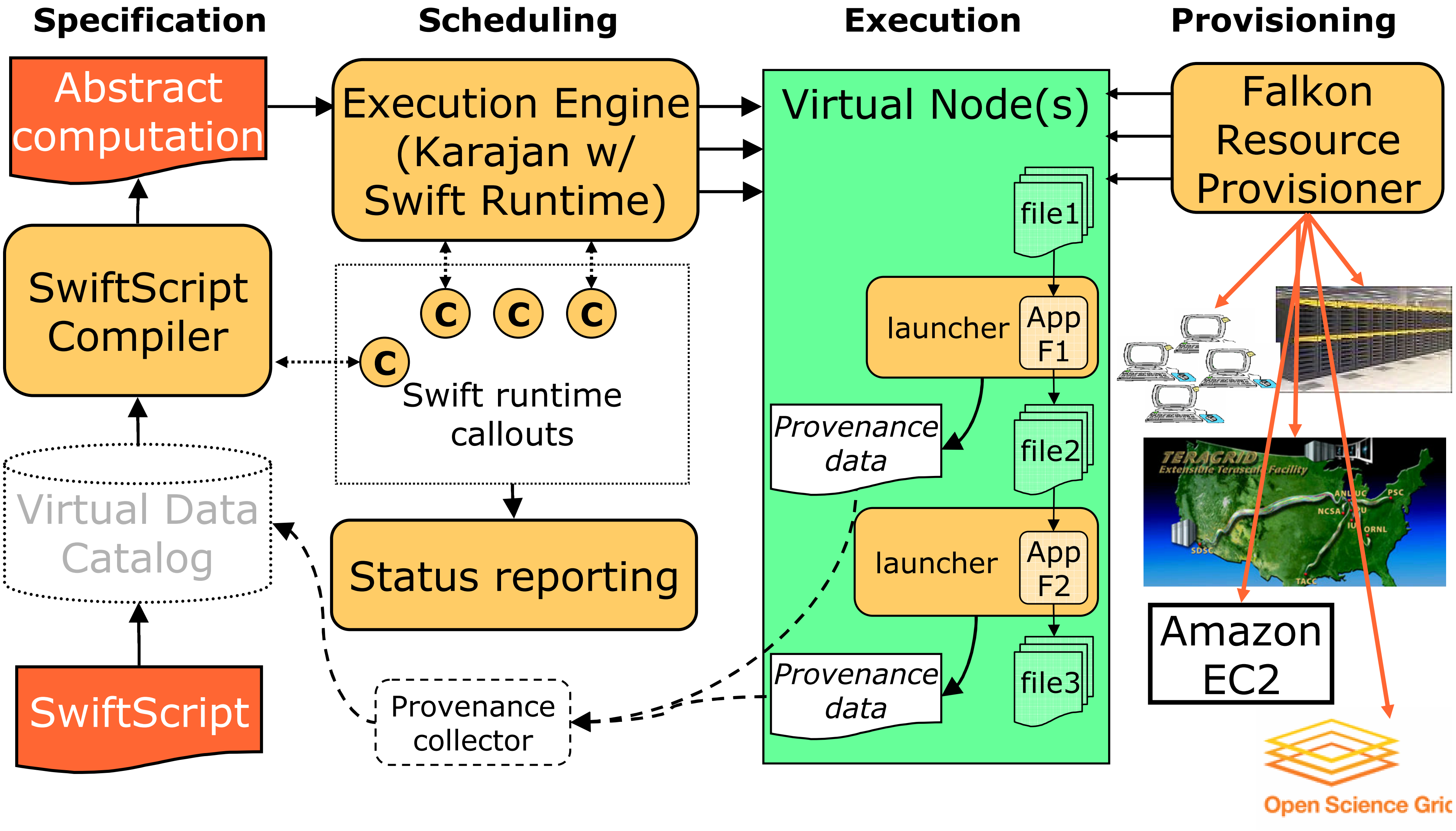
- Runtime system for SwiftScript
  - Translate programs into task graphs
  - Schedule, monitor, execute task graphs on local clusters and/or distributed Grid resources
  - Annotate data products with provenance metadata
- Grid scheduling and optimization
  - Lightweight execution engine: **Karajan**
  - **Falkon**: lightweight dispatch, dynamic provisioning
  - Grid execution: site selection, data movement
  - Caching, pipelining, clustering, load balancing
  - Fault tolerance, exception handling

A Virtual Data System for Representing, Querying & Automating Data Derivation [SSDBM02]

Swift Runtime: Related Work

- Multi-level scheduling [Banga99,Stankovic99]
- Condor glidein [Frey02], Condor Brick [Singh05,Mehta06], MyCluster [Walker06]
- Adaptive resource control [Appleby01], [Ramakrishnan06]
- Lightweight dispatch [Anderson04]

Swift Architecture



Specification

Abstract computation

SwiftScript Compiler

Virtual Data Catalog

SwiftScript

Scheduling

Execution Engine (Karajan w/ Swift Runtime)

C C C C

Swift runtime callouts

Status reporting

Provenance collector

Execution

Virtual Node(s)

file1

launcher App F1

Provenance data

file2

launcher App F2

Provenance data

file3

Provisioning

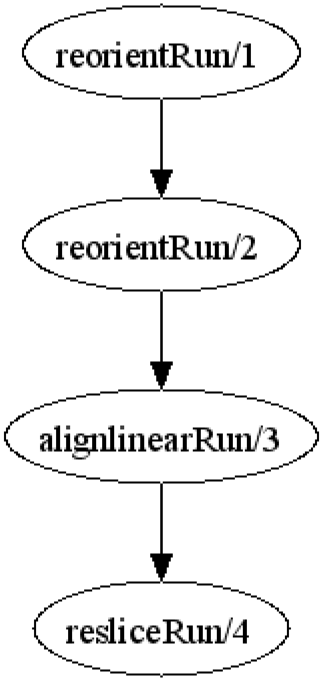
Falkon Resource Provisioner

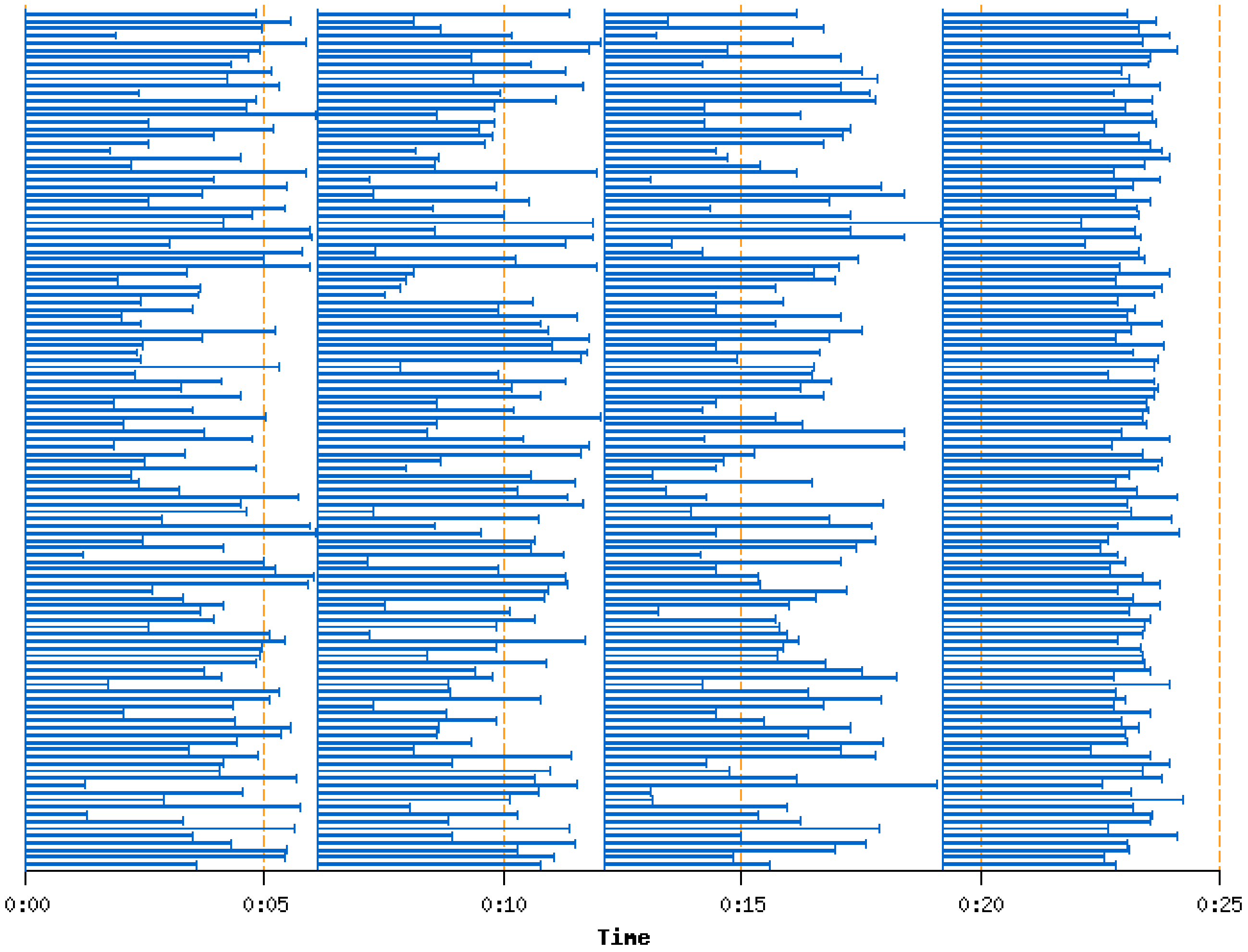
Amazon EC2

Swift uses **Karajan** Workflow Engine

- Fast, scalable threading model
- Suitable constructs for control flow
- Flexible task dependency model
  - “Futures” enable pipelining
- Flexible provider model allows for use of different run time environments
  - Job execution and data transfer
  - Flow controlled to avoid resource overload
- Workflow client runs from a Java container

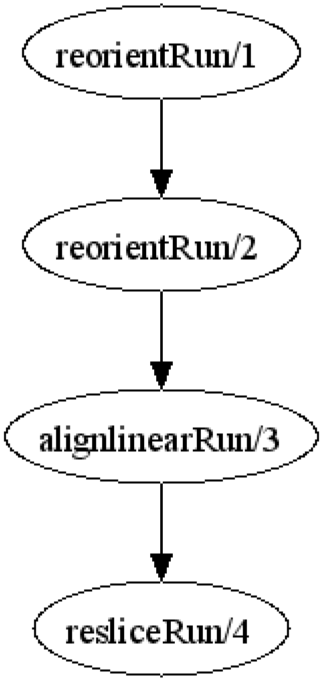
Karajan Futures Enable Pipelining


reorientRun/1
reorientRun/2
alignlinearRun/3
resliceRun/4



(Dispatch is performed here via GRAM+PBS)

Karajan Futures Enable Pipelining



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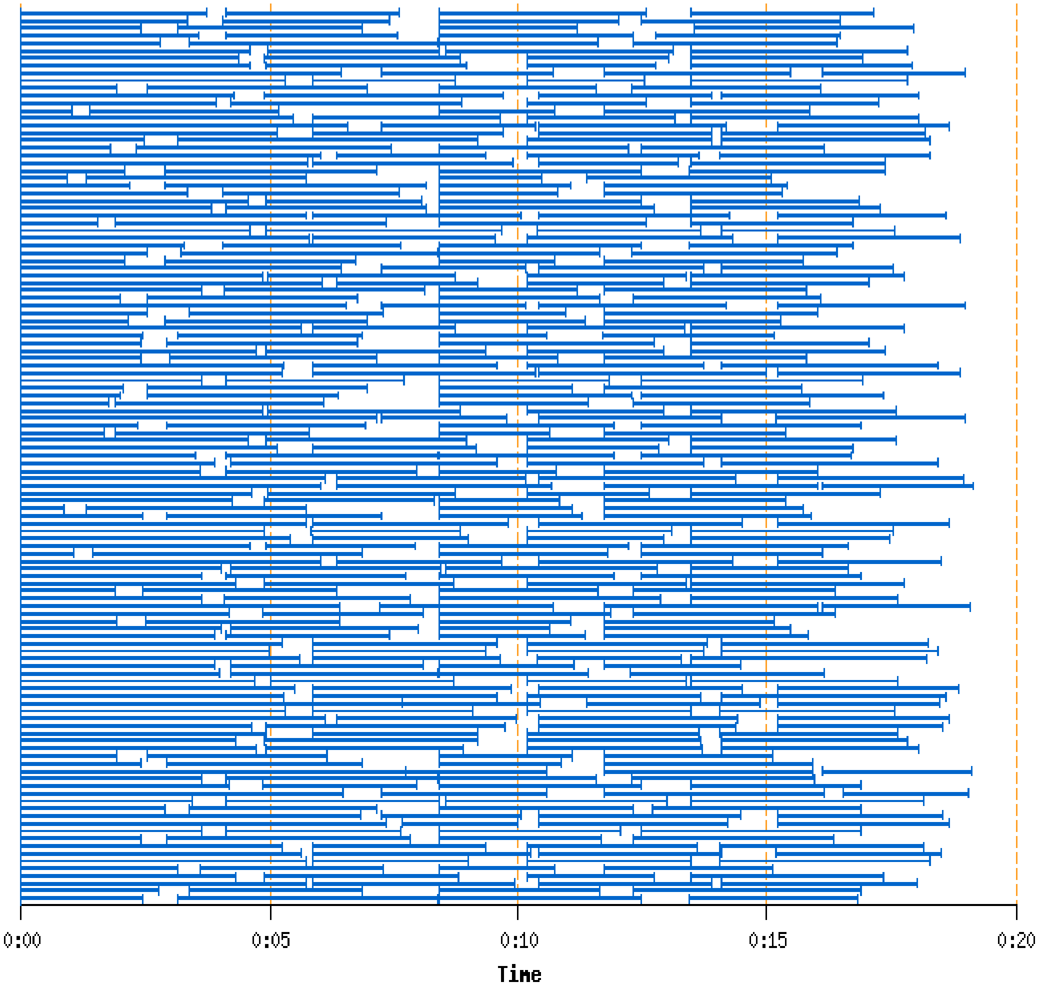

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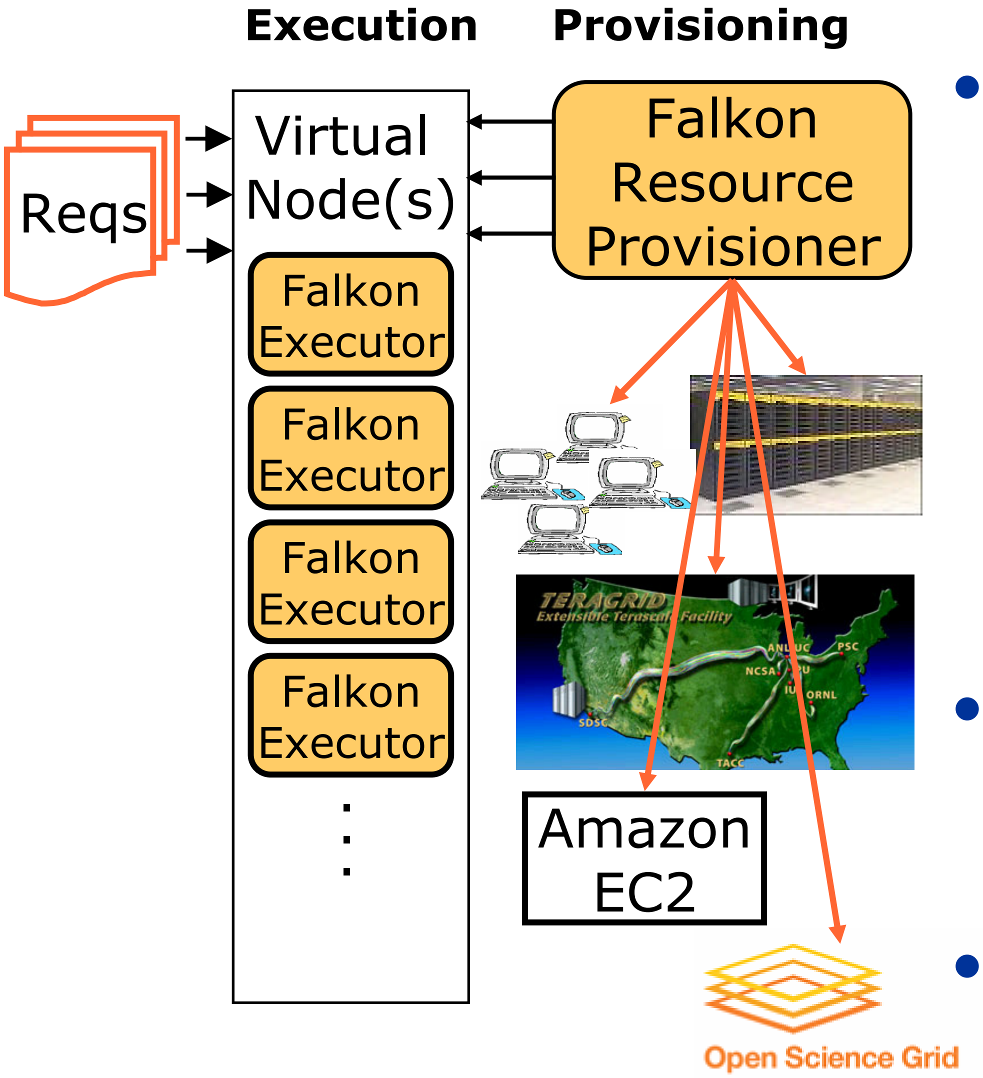
Swift Can Use **Falkon** Dispatcher & Provisioner



Execution

Provisioning

Reqs

Virtual Node(s)

Falkon Executor

Falkon Executor

Falkon Executor

Falkon Executor

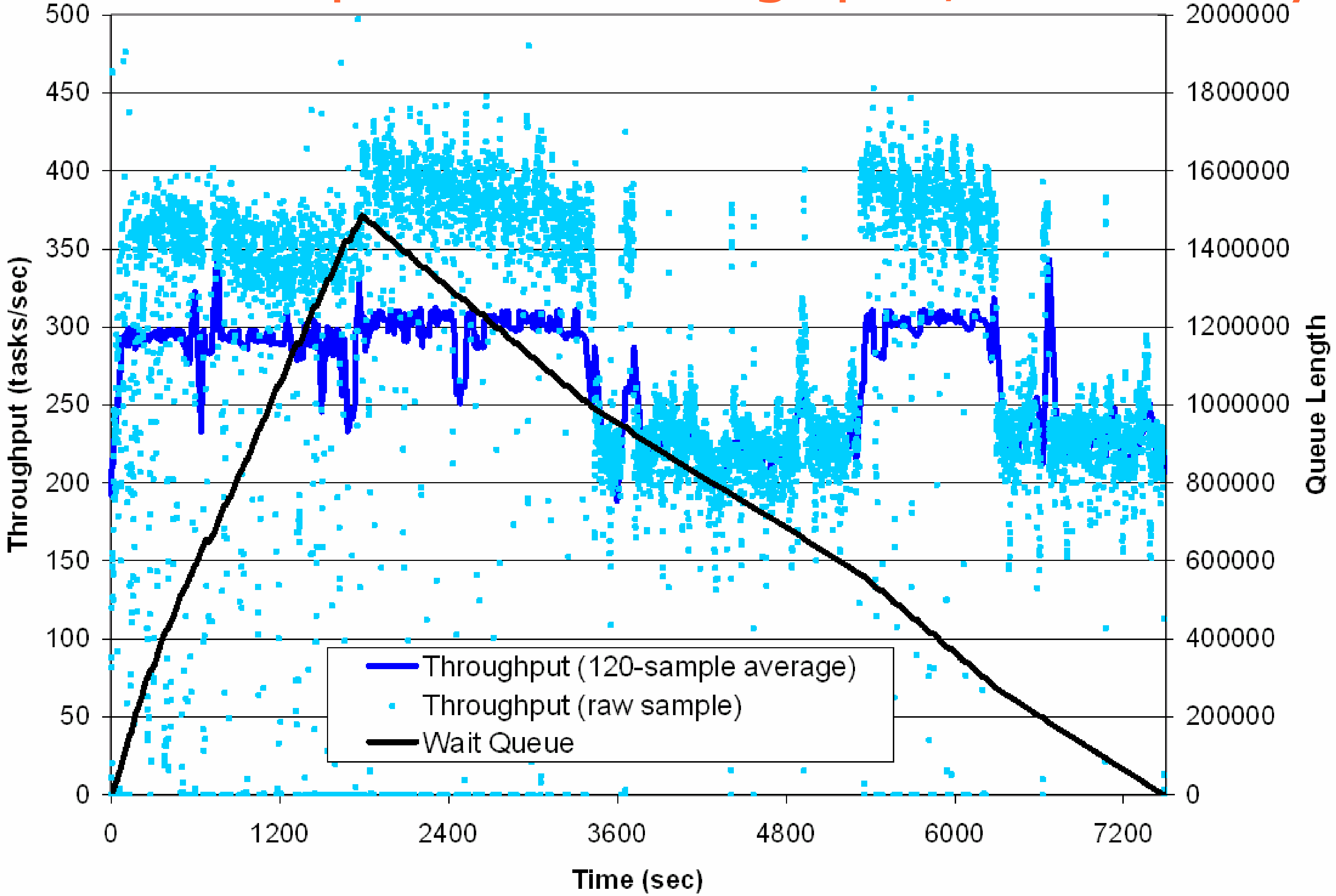
Falkon Resource Provisioner

Amazon EC2

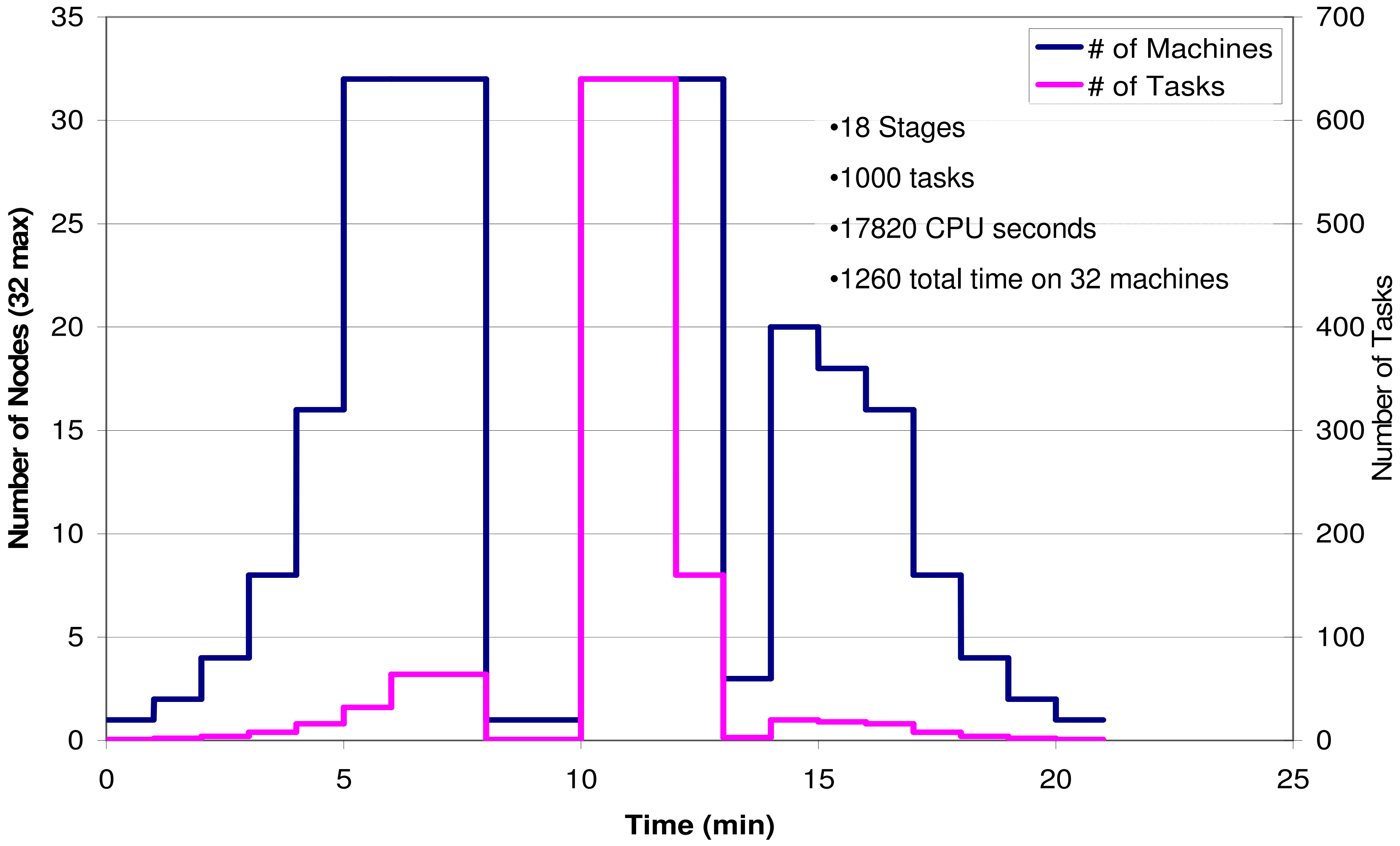
Open Science Grid

- Falkon provisioner:
  - Monitors **demand** (incoming user requests)
  - Manages **supply**: selects resources; creates executors (via Globus GRAM)
  - Various decision strategies for acquisition and release
- Falkon executor
  - Streamlined task dispatch
  - Driven by Karajan
- Dispatch to other executors also supported—e.g., GRAM

Falkon Dispatch: Throughput, Scalability

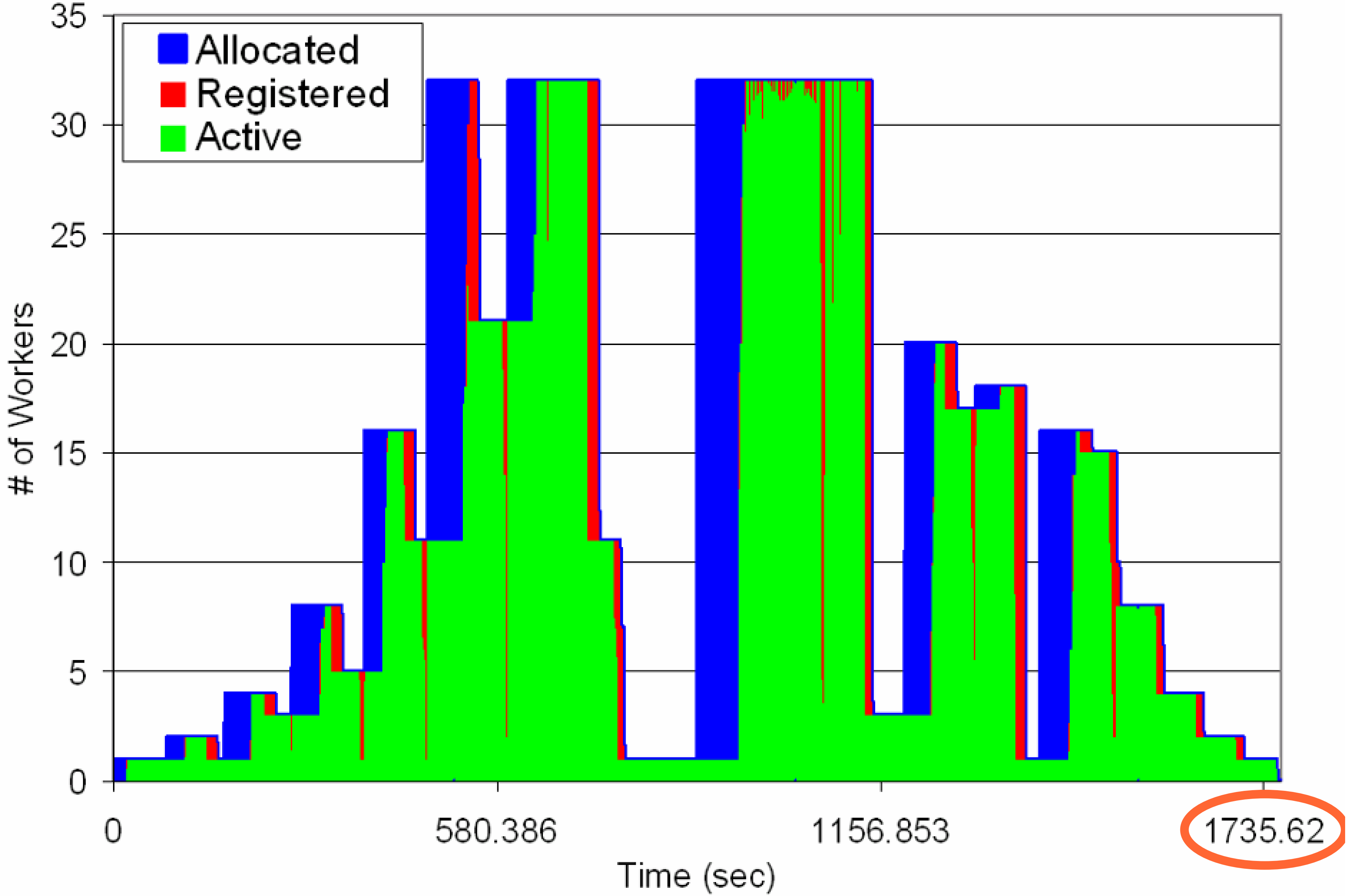


Falkon Provisioning: Synthetic Benchmark



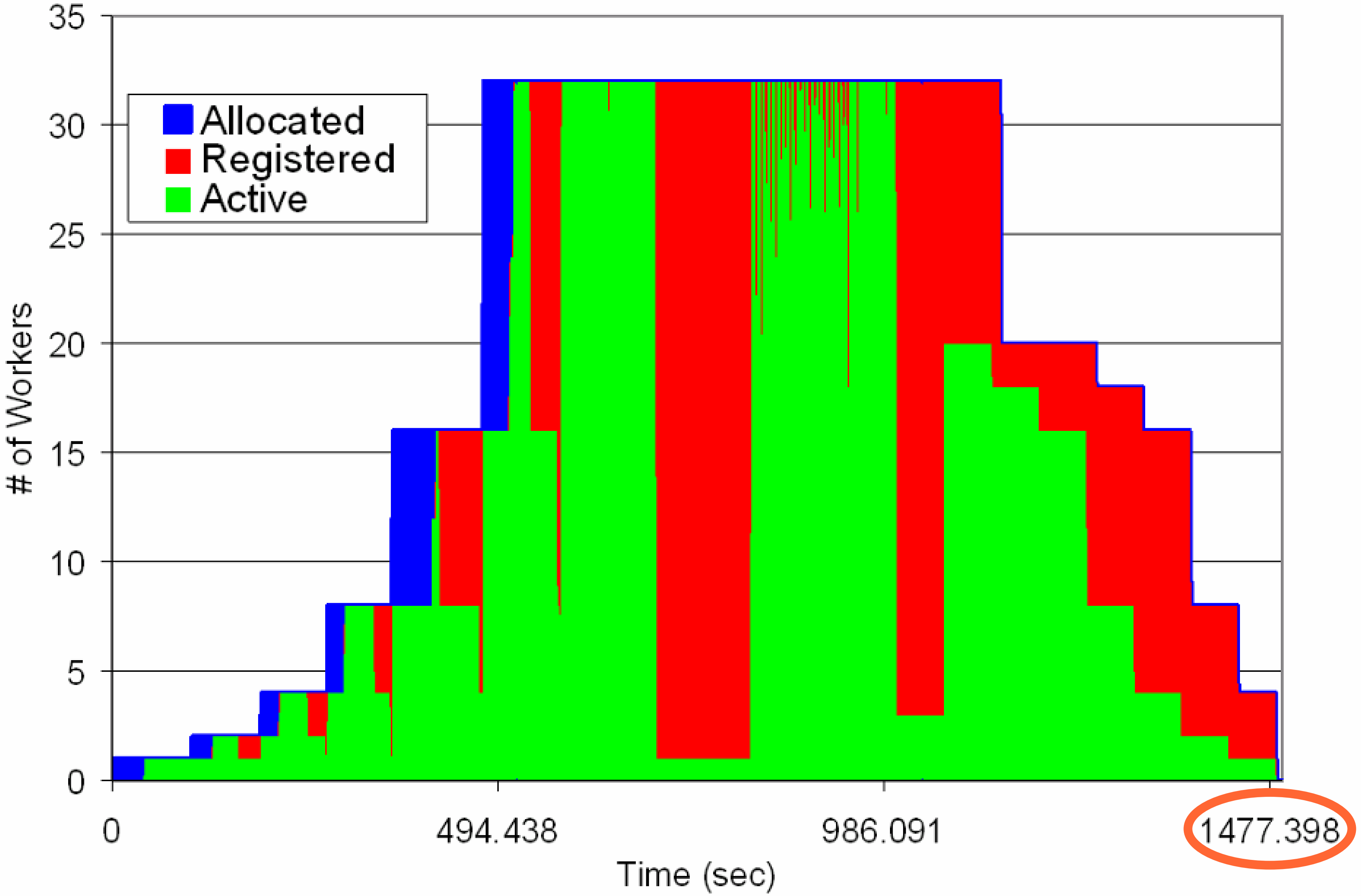
- 18 Stages
- 1000 tasks
- 17820 CPU seconds
- 1260 total time on 32 machines

Release after 15 Seconds Idle

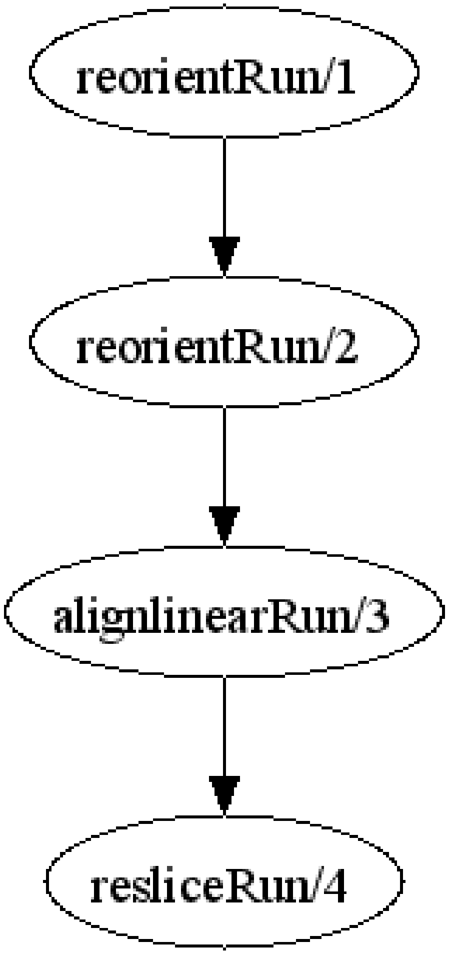


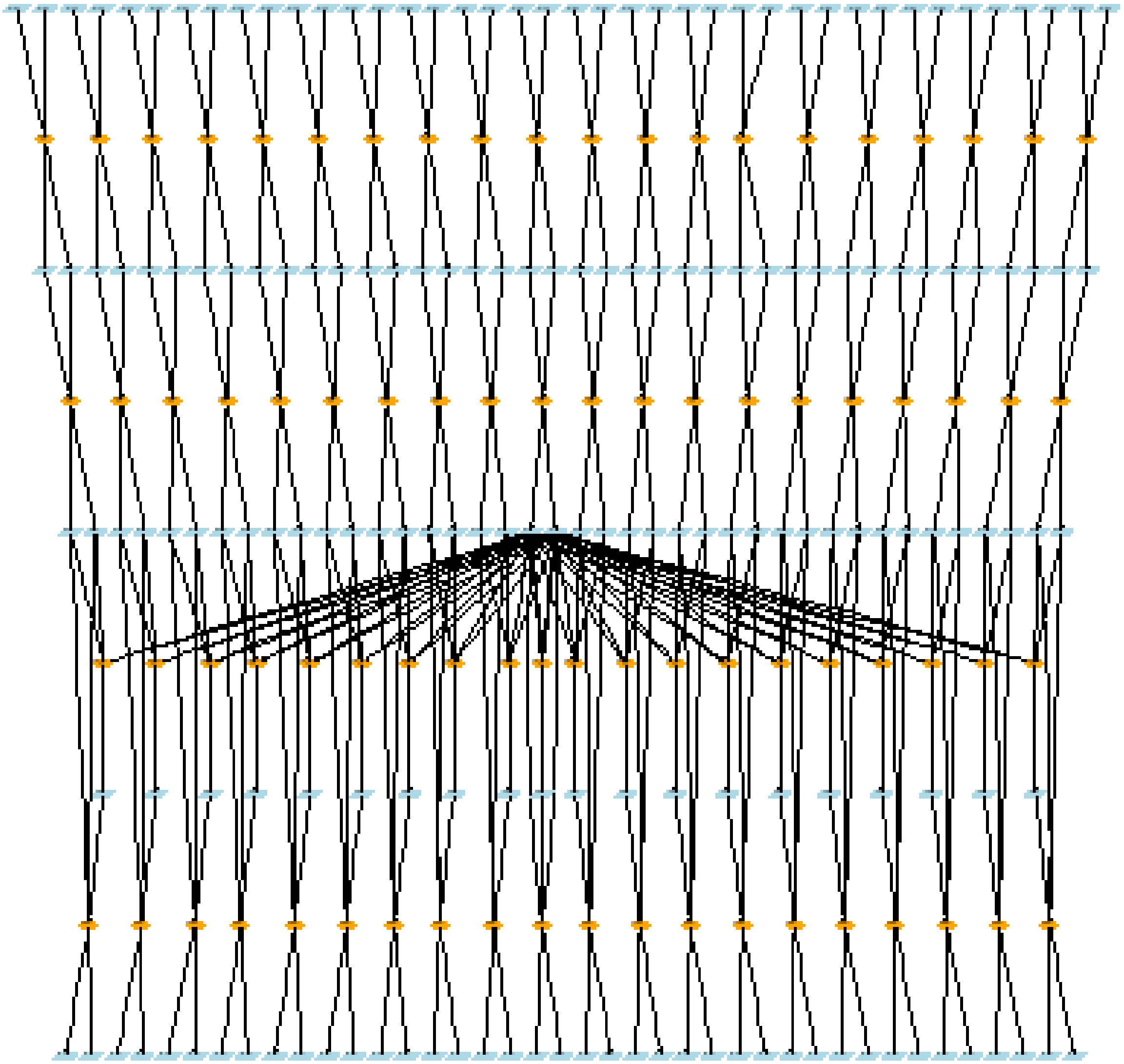
Ioan Raicu & Yong Zhao, U.Chicago

Release after 180 Seconds Idle



Swift Application Performance: fMRI Task Graph





Yong Zhao and Ioan Raicu, U.Chicago

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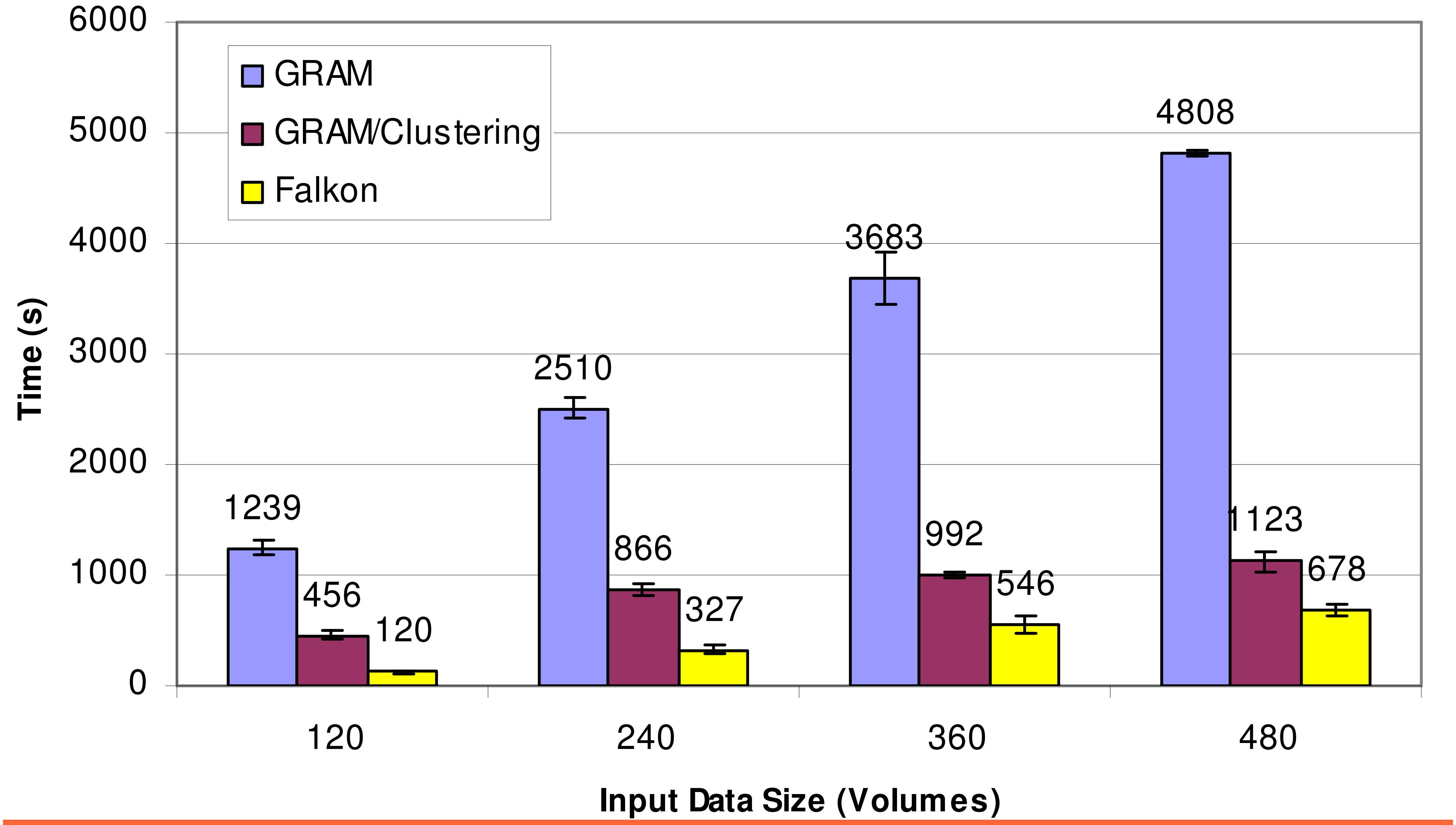
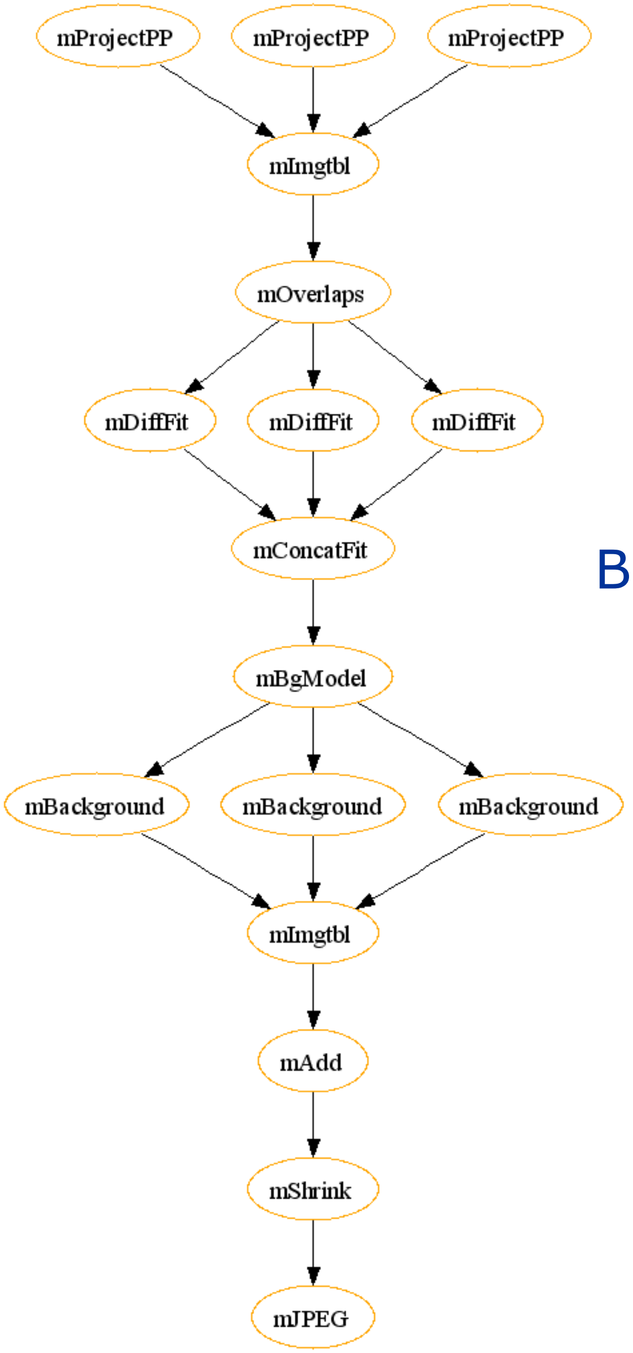
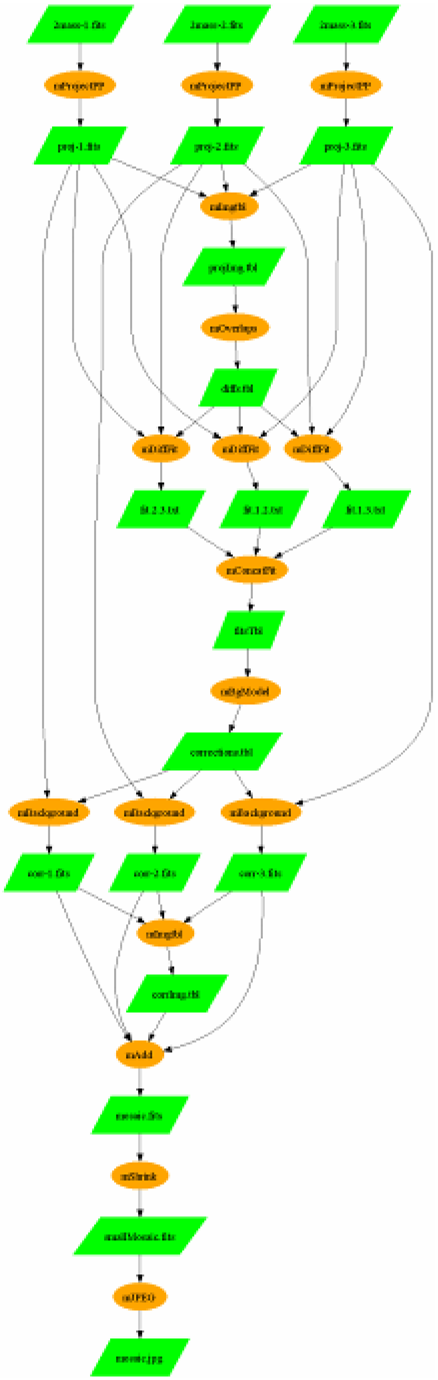


Yong Zhao and Ioan Raicu, U.Chicago

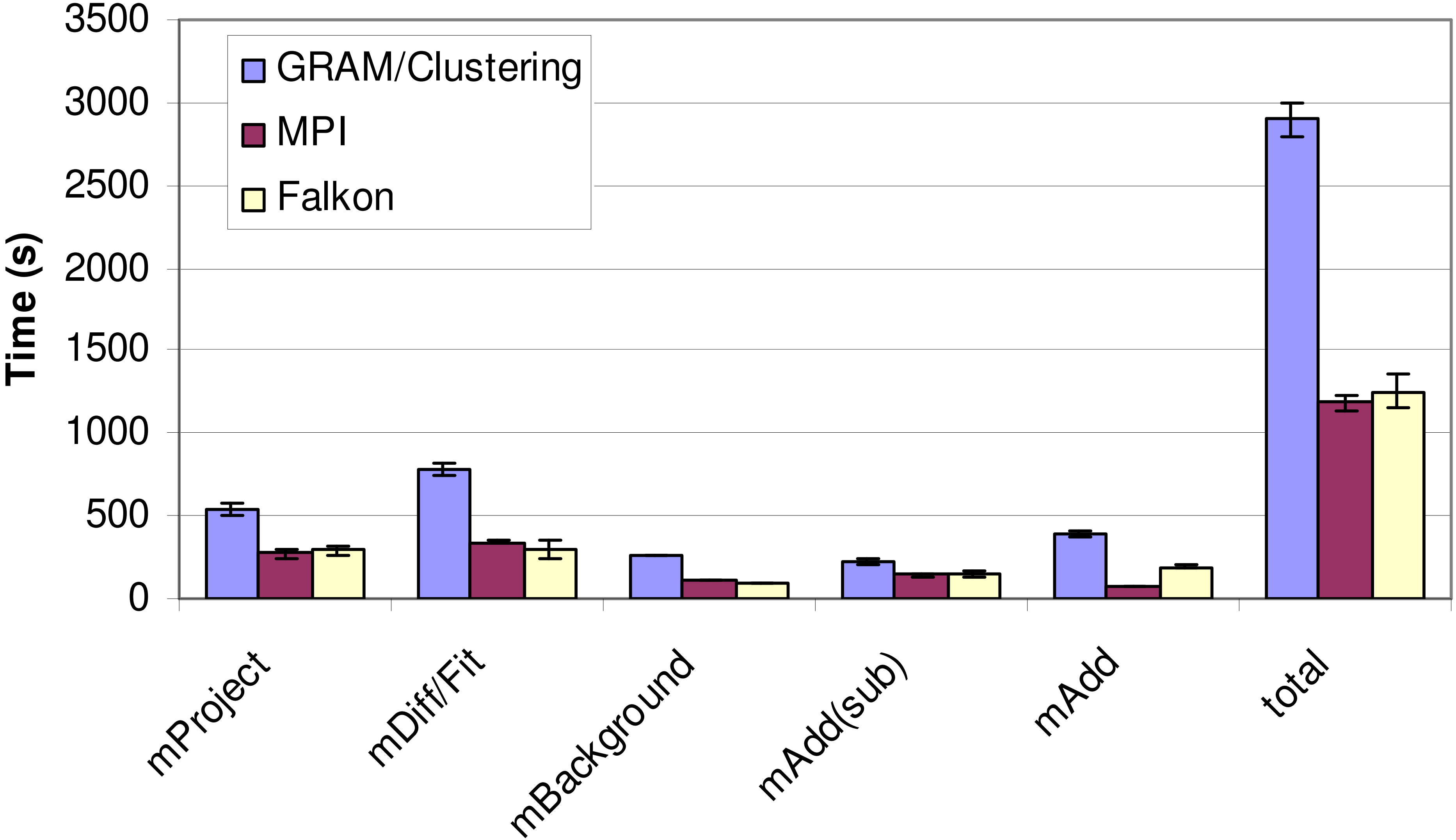
Swift Application



B. Berriman, J. Good (Caltech)
J. Jacob, D. Katz (JPL)



Montage



Yong Zhao and Ioan Raicu, U.Chicago

Other Swift Applications Include …

Application	#Jobs/computation	Levels
ATLAS* HEP Event Simulation	500K	1
fMRI AIRSN Image Processing	100s	12
FOAM* Ocean/Atmosphere Model	2000 (250 8-CPU jobs)	3
GADU* Genomics: (14M seq. analyzed)	40K	4
fMRI Aphasia Study	500	4
NVO/NASA Montage	1000s	16
QuarkNet/I2U2*+ Physics Science Education	10s	3-6
RadCAD: Radiology Classifier Training	1000s	5
SIDGrid: EEG Wavelet Proc, Gaze Analysis, …	100s	20
SDSS* Coadd, Cluster Search	40K, 500K	2, 8

* Using predecessor **Virtual Data System** (VDS)

+ Collaborative science learning & education: 18 experiments, 51 universities/labs, 500+ schools, 100,000 students

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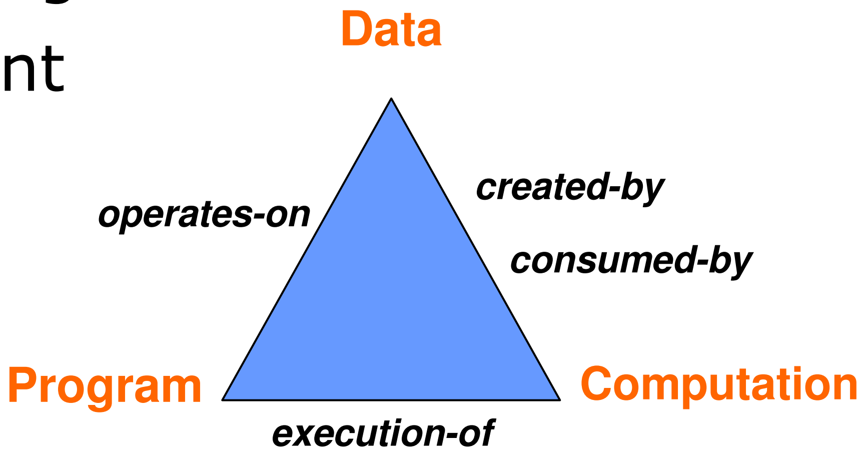
VDC

Virtual Data Concept

- Capture information about relationships among
  - Data (varying locations and representations)
  - Programs (& inputs, outputs, constraints)
  - Computations (& execution environments)
- Apply this information to:
  - Discovery of data and programs
  - Computation management
  - Provenance
  - Planning and scheduling
  - Performance optimization



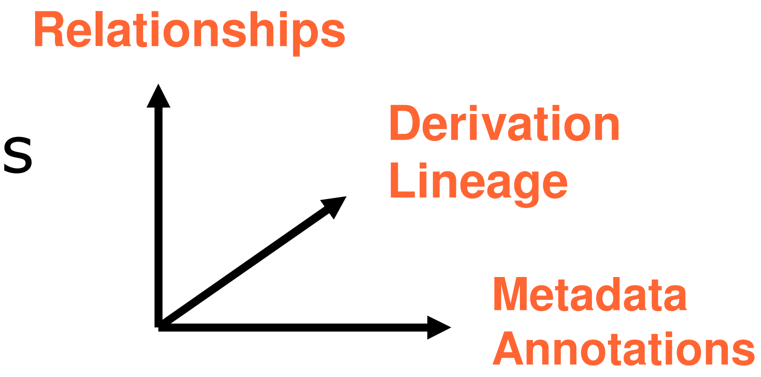
A Virtual Data System for Representing, Querying & Automating Data Derivation [SSDBM02]

Provenance – Related Work

- Database
  - Determine the source of tuples [Cui,Widom00]
  - Why and where [Buneman,Khanna01]
- Scientific
  - Logbook [Myers,Chappell03] [Bourilkov,Khandelwal06]
- Service
  - P-assertions [Szomszor,Moreau03]
- Other
  - PASS [Muniswamy-Reddy,Holland06]

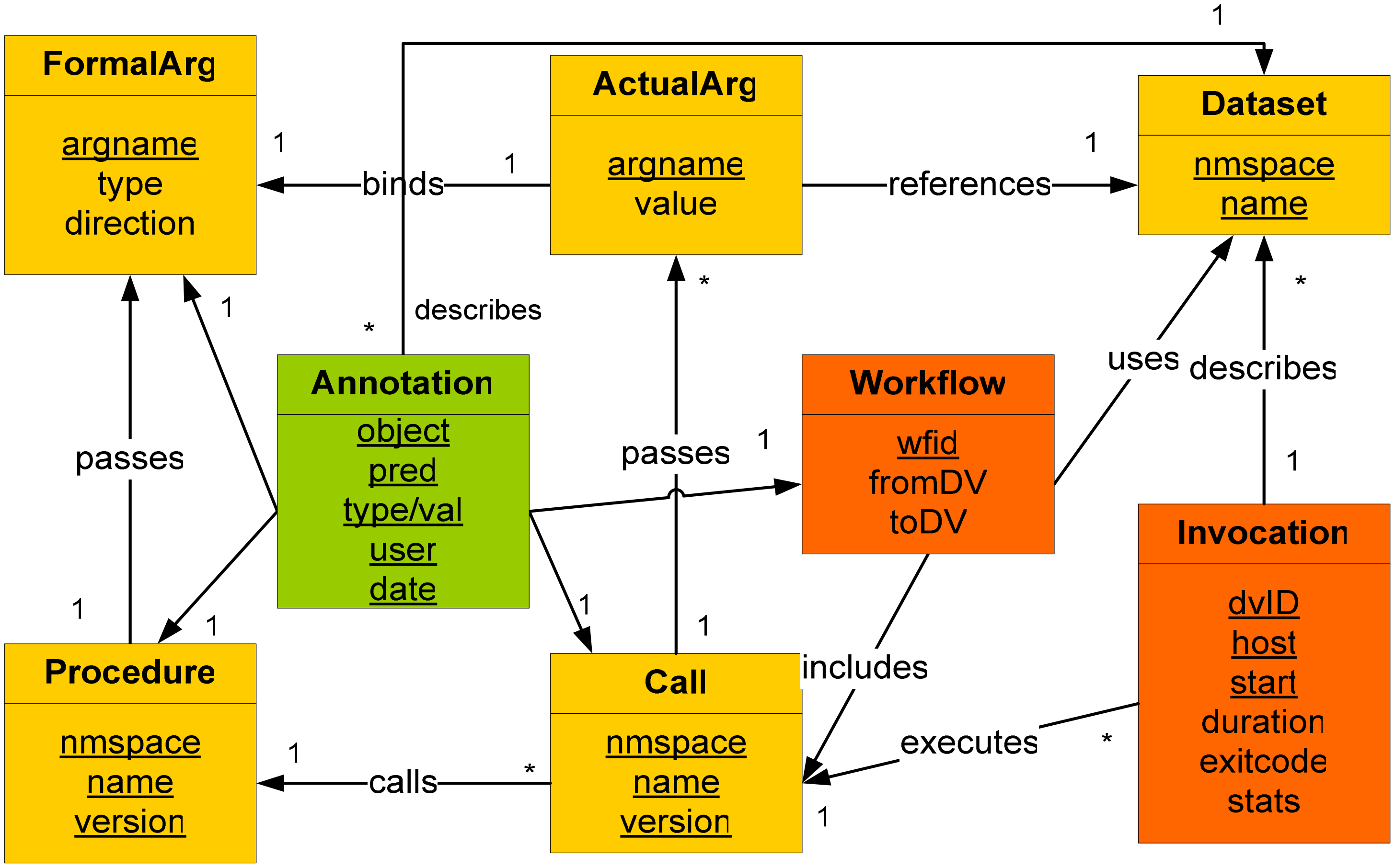
Provenance Model

- Temporal aspect
  - **Prospective** provenance
    - Recipes for how to produce data
    - Metadata annotations about procedures and data
  - **Retrospective** provenance [GCE06]
    - Invocation records of run time environments and resources used: site, host, executable, execution time, file stats ...
- Dimensional aspect
  - **Virtual data** relationships
  - **Derivation** lineage
  - **Metadata** annotations

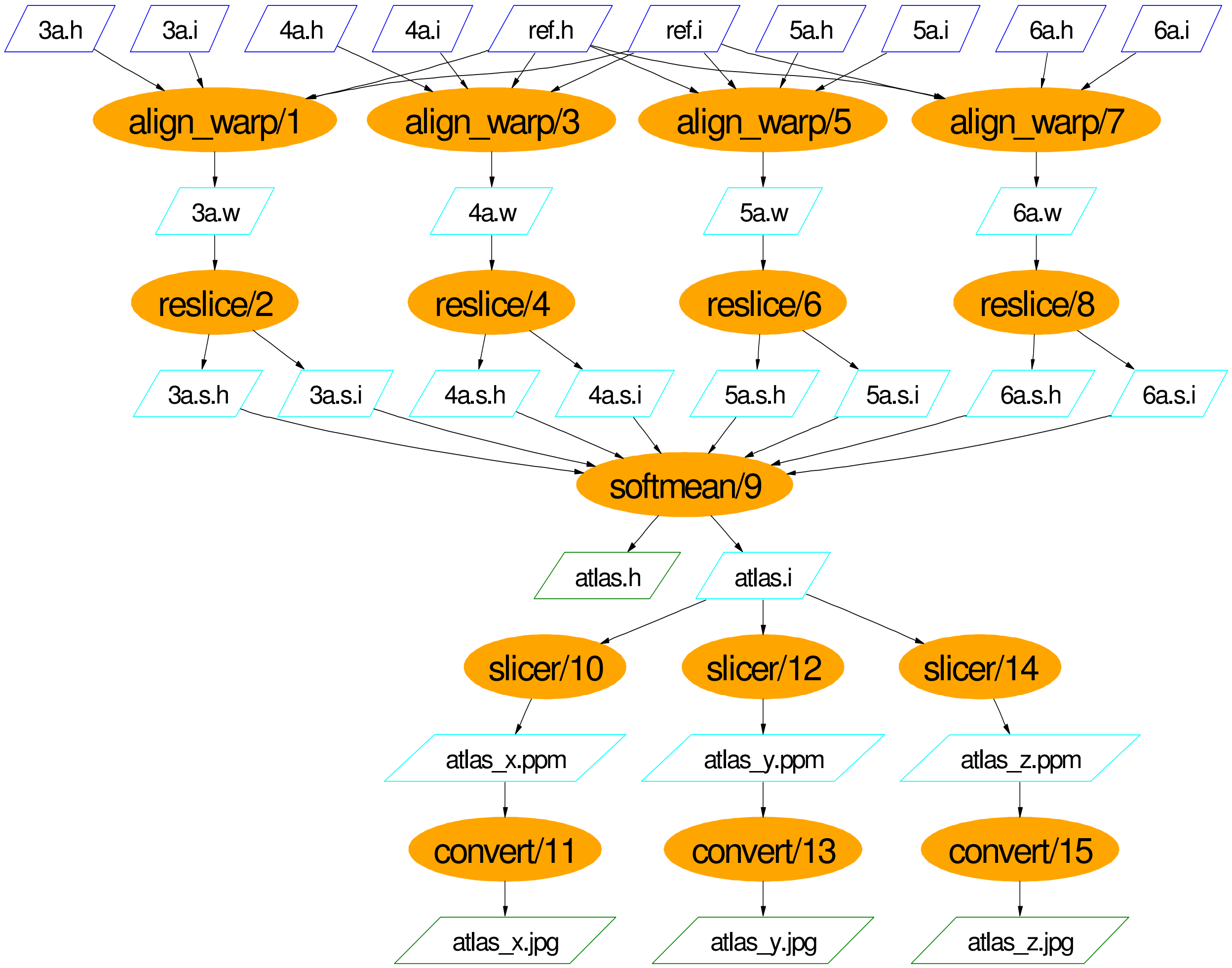


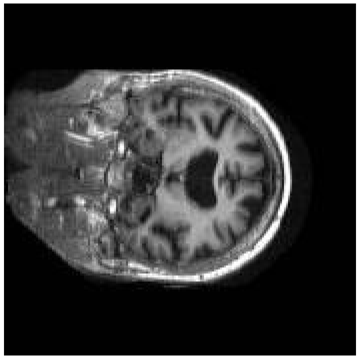
Applying the Virtual Data Provenance Model [IPAW06]

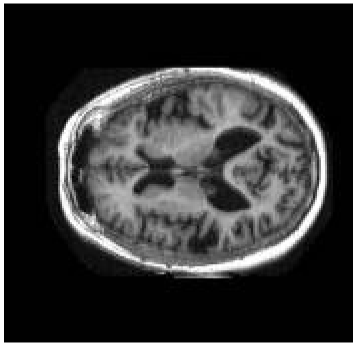
Virtual Data Schema

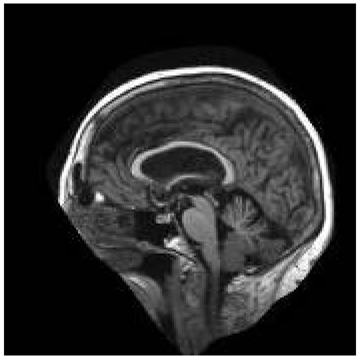


Query Context: fMRI Analysis









First Provenance Challenge, http://twiki.ipaw.info/ [CCPE06]

Query Examples

- Query by procedure signature
  - Show procedures that have inputs of type *subjectImage* and output types of *warp*
- Query by actual arguments
  - Show *align_warp* calls (including all arguments), with argument *model=rigid*
- Query by annotation
  - List anonymized subject images for young subjects:
    - Find datasets of type *subjectImage* , annotated with *privacy=anonymized* and *subjectType=young*
- Basic lineage graph queries
  - Find all datasets derived from dataset ‘5a’
- Graph pattern matching
  - Show me all output datasets of *softmean* calls that were aligned with *model=affine*
- Multi-dimensional query

Acknowledgements

- Swift effort is supported by NSF (I2U2, iVDGL), NIH, UChicago/Argonne Computation Institute
- Swift team
  - Ben Clifford, Ian Foster, Mihael Hategan, Veronika Nefedova, Ioan Raicu, Mike Wilde, Yong Zhao
- Java CoG Kit
  - Mihael Hategan, Gregor Von Laszewski, and many collaborators
- User contributed workflows and application use
  - I2U2, ASCI Flash, U.Chicago Molecular Dynamics, U.Chicago Radiology, Human Neuroscience Lab

Future Work

- XDTM
  - Support for services as well as applications
  - Greater abstraction in mappers; databases
- SwiftScript
  - Exceptions
  - Event-driven dispatch & execution
- Falkon
  - Scale to more resources; data caching
  - Support for service workloads
- VDC
  - Integration into Swift; collaboration support
  - Experiments at scale

Swift: Summary

- Clean separation of logical/physical concerns
  - ◆ XDTM specification of logical data structures

+ Concise specification of parallel programs

- ◆ SwiftScript, with iteration, etc.

+ Efficient execution (on distributed resources)

- ◆ **Karajan+Falkon**: Grid interface, lightweight dispatch, pipelining, clustering, provisioning

+ Rigorous provenance tracking and query

- ◆ Virtual data schema & automated recording

→ **Improved usability and productivity**

- ◆ Demonstrated in numerous applications

http://www.ci.uchicago.edu/swift

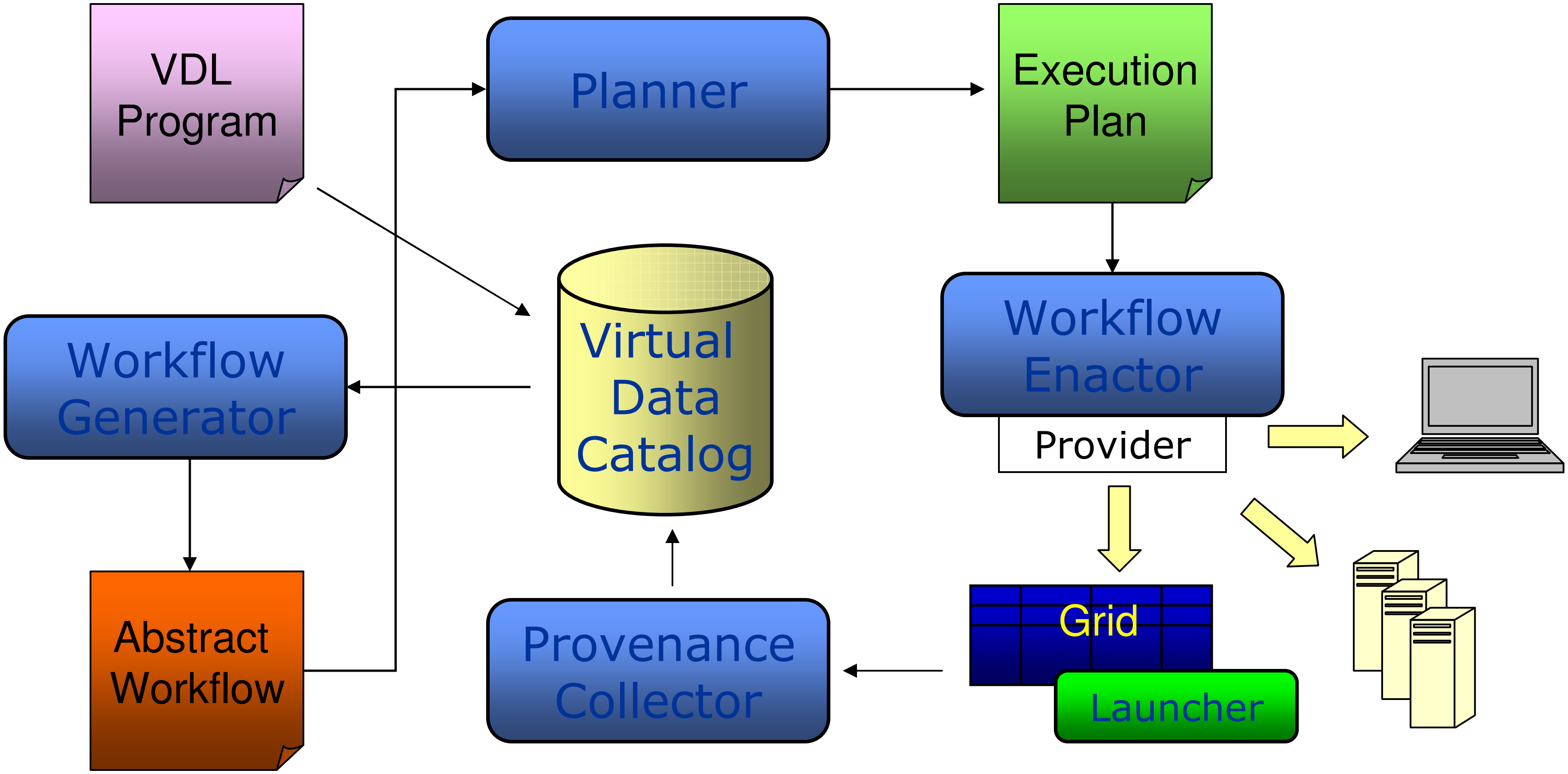
Thank You!

Extra Slides

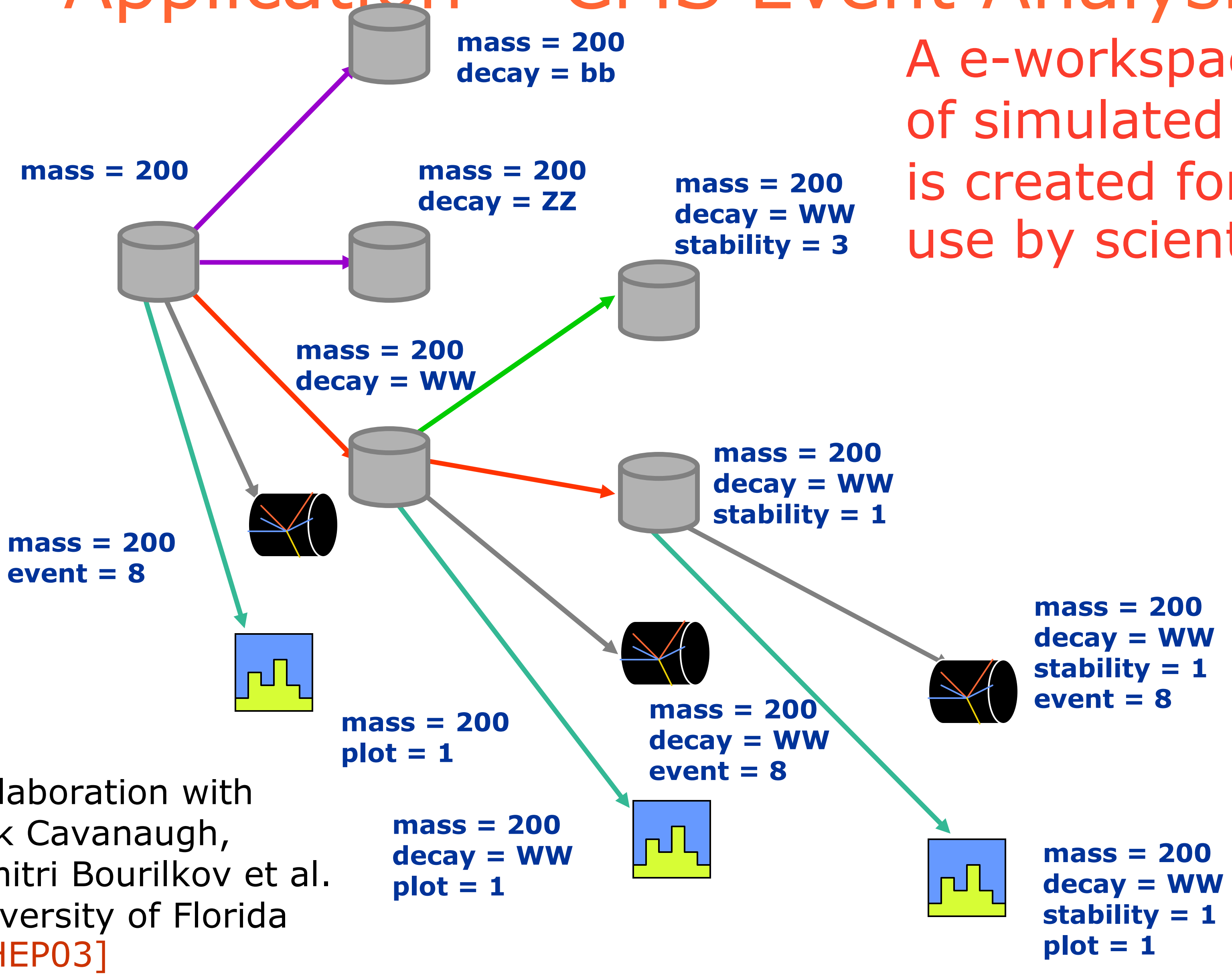
XDTM – Related Work

Features\Model	XDTM	DFDL	PADS/PADX	SDO
Data Format	Any	Binary file format	Ad hoc data source	Any
Abstract Data Model	Declarative description XML Schema	XML Schema	Declarative description XML Schema	Disconnected data graph
Physical Information	Mapping descriptor	Annotation embedded in XML schema	Mixed with declaration	N/A
Logical/Physical Separation	Yes	No	No	Yes
Mapping Specification	Mapping interface	No	No	Data Access Service

VDS – System Diagram



Application – CMS Event Analysis



A e-workspace
of simulated data
is created for future
use by scientists...

Collaboration with
Rick Cavanaugh,
Dimitri Bourilkov et al.
University of Florida
[CHEP03]

ATLAS Large Scale Simulation

"How much compute time was delivered?"
(BNL, 1475+ CPUs)

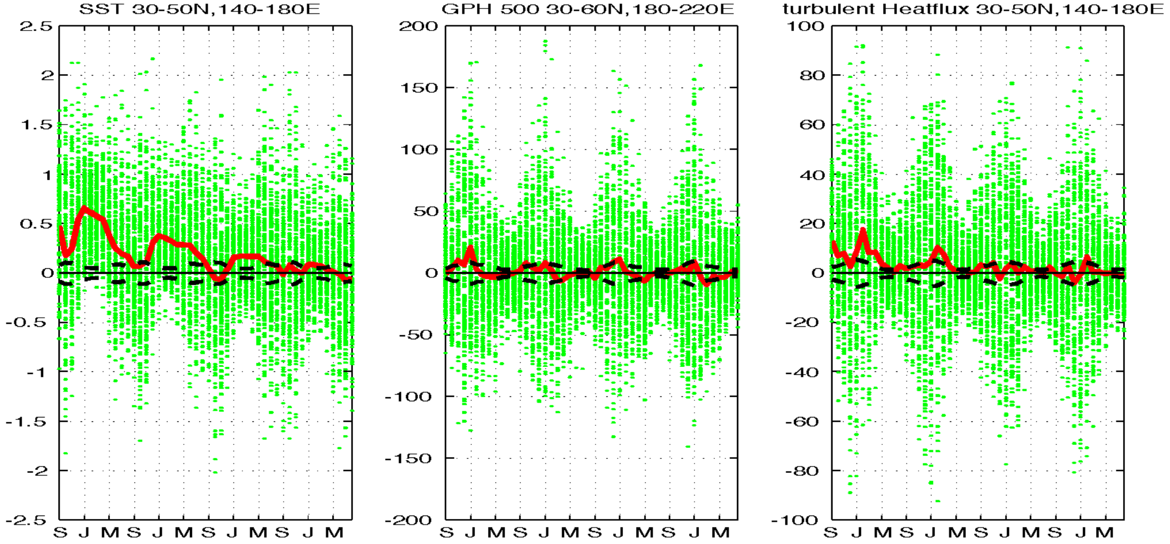
CPU years	Jobs	Month
0.45	1402	2004-06
19.88	13267	2004-07
33.88	20678	2004-08
40.06	20229	2004-09
15.21	30833	2004-10
14.95	34591	2004-11

Fast Ocean Atmosphere Model

160 ensemble members = 2.5 months to run

NCAR

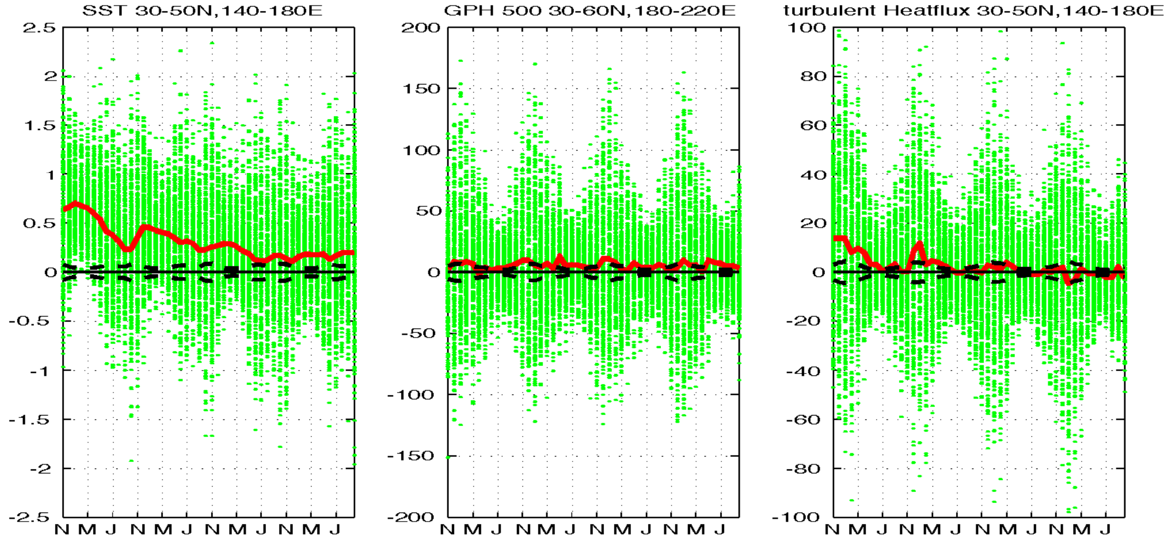
Manual config, execution, bookkeeping



250 ensemble members = 4 days to run

VDS on Teragrid

Automated



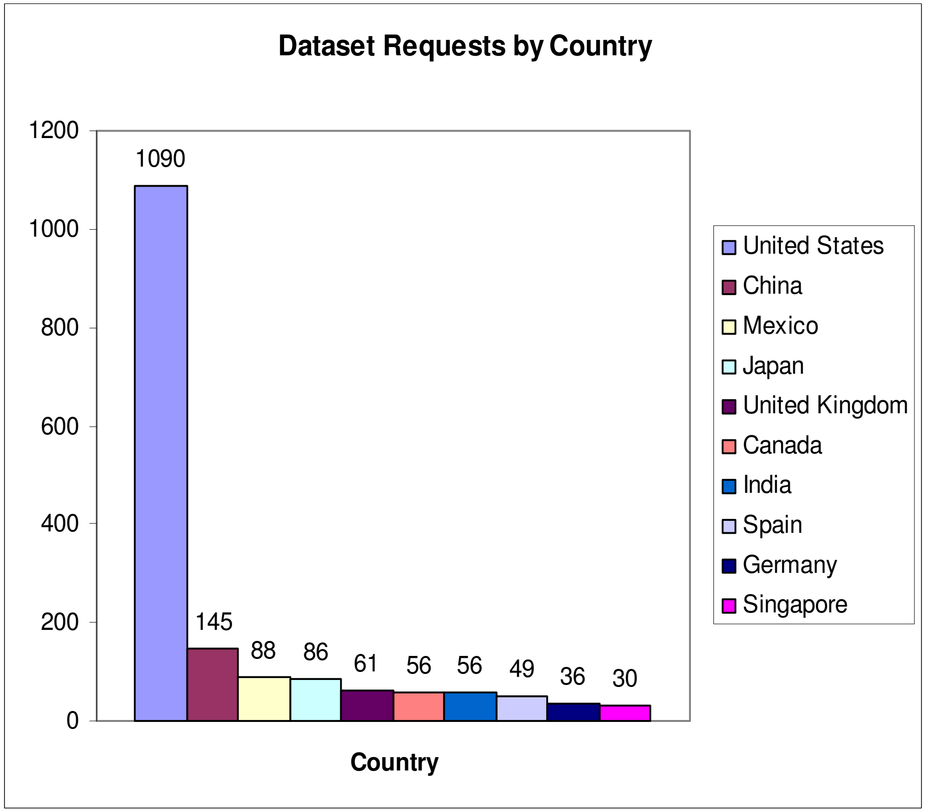
Green: each ensemble Red: ensemble mean

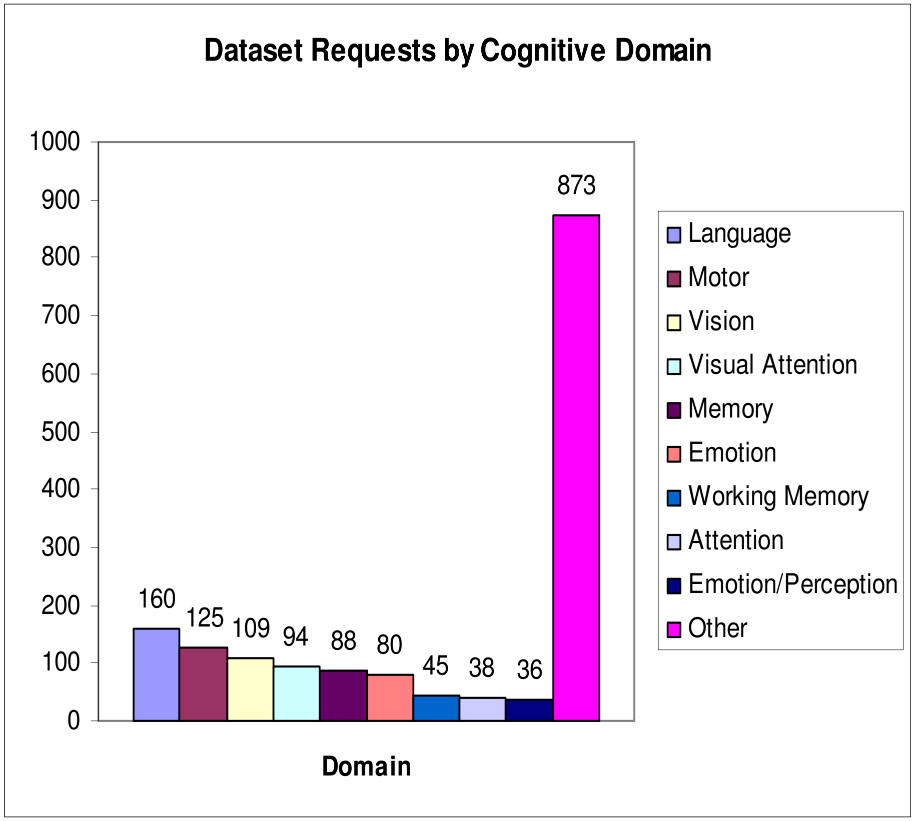
Visualization courtesy Pat Behling and Yun Liu, UW Madison

Radiology Example

```
type Image {}
type Center {}
type ROI { Image image; Center center; }
type ROIVec {
   ROI roi[];
}

(AzInfo az) LDAClassify (ROIVec malROIs, ROIVec benROIs, Parameter
param, FeatureNames fn) {
    ….
}

ROIVec malROIs<roi_mapper;location="malROI/">;
ROIVec benROIs<roi_mapper;location="benROI/">;
Parameter param<"SegNExtract.params">;
FeatureNames featureList<"feat-names.lst">;

AzInfo az<"LDA_Az.out">;
az = LDAClassify(malROIs, benROIs, param, featureList);
```

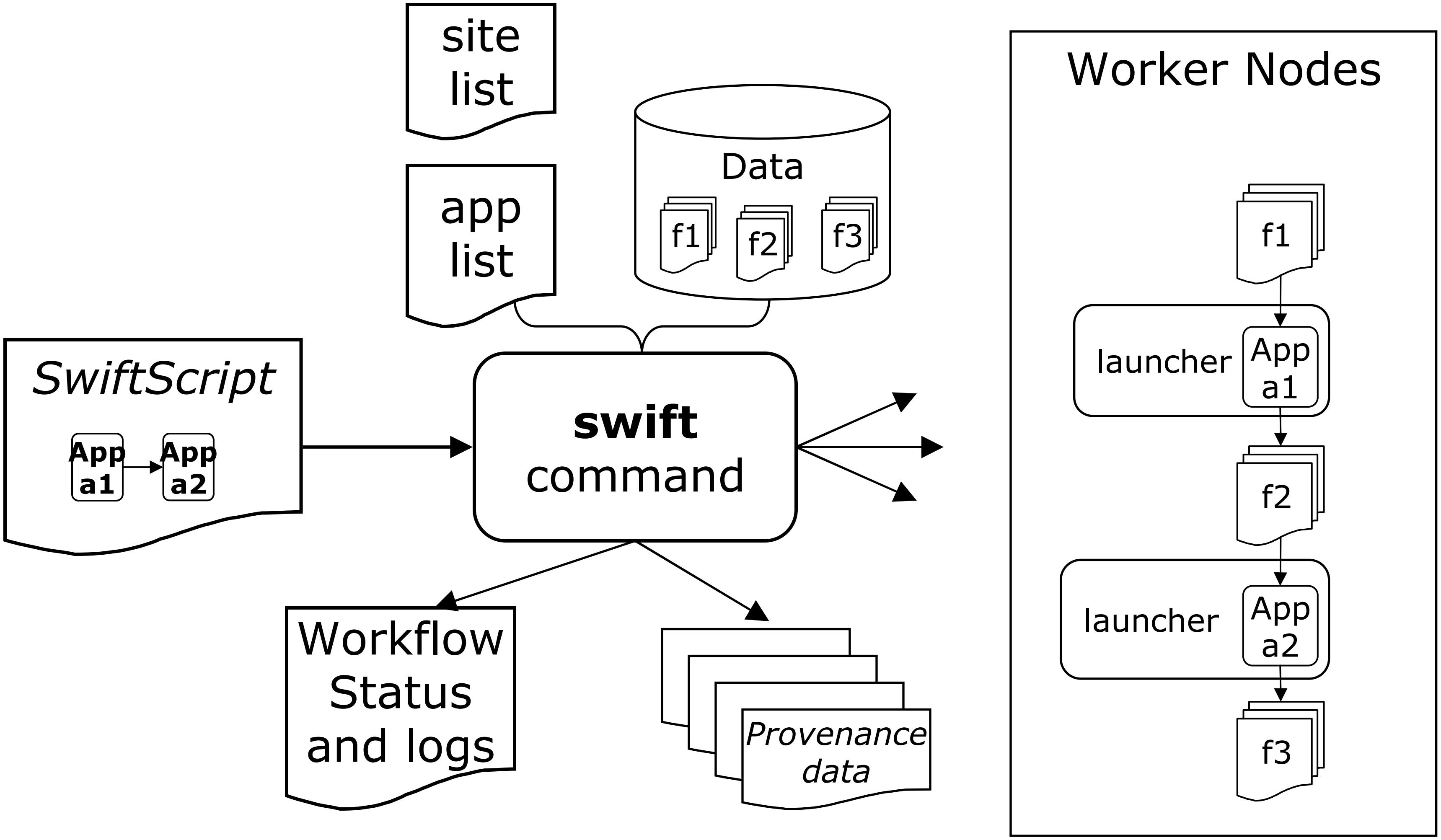
An International Community


Dataset Requests by Country


Dataset Requests by Cognitive Domain

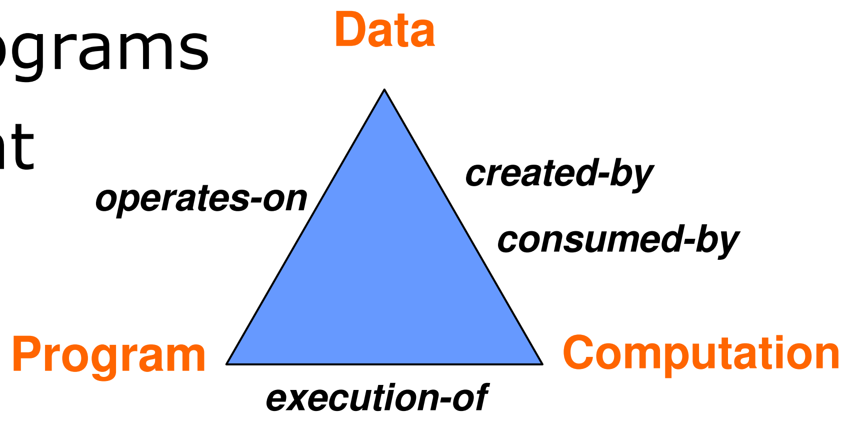
Data source: since Oct. 2003, http://www.fmridc.org

Using Swift


site list
app list
Data
f1
f2
f3
Worker Nodes
SwiftScript
App a1
App a2
swift command
f1
launcher
App a1
f2
launcher
App a2
f3
Workflow Status and logs
Provenance data

Virtual Data Concept (1)

- Capture information about relationships among
  - Data (varying locations and representations)
  - Programs (& inputs, outputs, constraints)
  - Computations (& execution environments)
- Apply this information to:
  - Discovery of data and programs
  - Computation management
  - Provenance
  - Planning and scheduling
  - Performance optimization



Virtual Data Concept (2)

- Location transparency
  - Data processing independent of location
  - Replica location service, selection service
- Materialization transparency
  - Recipes for data derivation
- Physical representation transparency
  - Logical descriptions and relations

Virtual Data System (VDS)

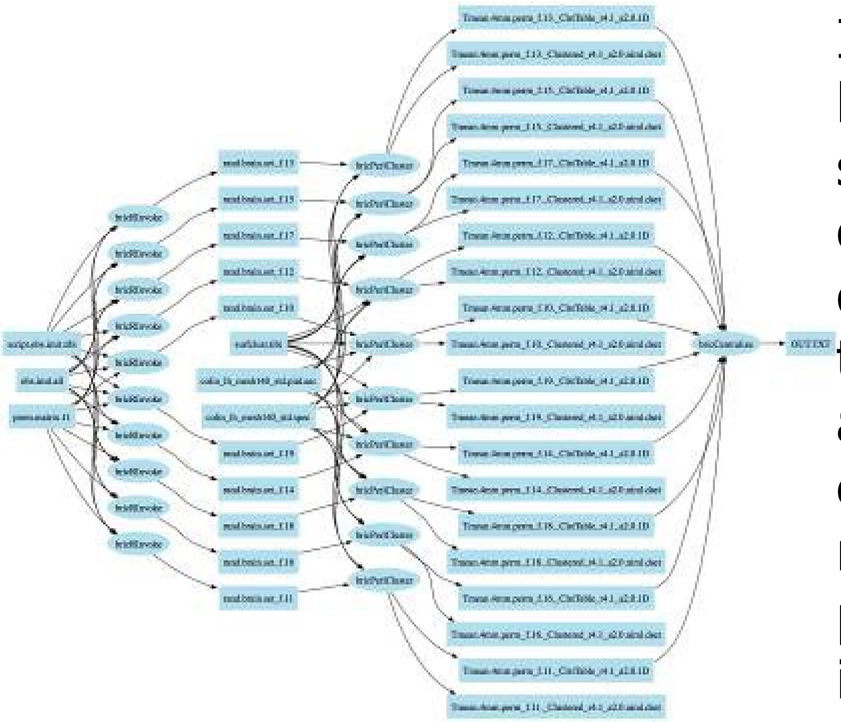
- Introduced Virtual Data Language (VDL)
  - A location-independent parallel language
- Several planners, e.g.:
  - Pegasus: main production planner
  - Euryale: experimental “just in time” planner
  - GADU/GNARE: user application planner (D. Sulahke, Argonne)
- Provenance
  - Kickstart: app launcher and tracker
  - VDC: virtual data catalog

A Virtual Data System for Representing, Querying & Automating Data Derivation [SSDBM02]

VDL/VDS Limitations

- Missing language features
  - Data typing & data mapping
  - Iterators & control-flow constructs
- Run time complexity in VDS
  - State explosion for data-parallel applications
  - Computation status hard to provide
  - Debugging information complex & distributed
- Performance
  - Still many runtime bottlenecks

Swift Application Example: ACTIVAL: Neural Activation Validation



Identifies clusters of neural activity not likely to be active by random chance: switch labels of the conditions for one or more participants; calculate the delta values in each voxel, re-calculate the reliability of delta in each voxel, and evaluate clusters found. If the clusters in data are greater than the majority of the clusters found in the permutations, then the null hypothesis is refuted indicating that clusters of activity found in our experiment are not likely to be found by chance.

Work by S. Small,
U. Hasson, UChicago.

SwiftScript Program ACTIVAL – Datatypes & Utilities

```
type script {}                                  type fullBrainData {}
type brainMeasurements{}                        type fullBrainSpecs {}
type precomputedPermutations{}                  type brainDataset {}
type brainClusterTable {}
type brainDatasets{ brainDataset b[]; }
type brainClusters{ brainClusterTable c[]; }

// Procedure to run "R" statistical package
(brainDataset t) bricRInvoke (script permutationScript, int iterationNo,
   brainMeasurements dataAll, precomputedPermutations dataPerm) {
     app { bricRInvoke @filename(permutationScript) iterationNo
                     @filename(dataAll) @filename(dataPerm); }
}

// Procedure to run AFNI Clustering tool
(brainClusterTable v, brainDataset t) bricCluster (script clusterScript,
  int iterationNo, brainDataset randBrain, fullBrainData brainFile,
  fullBrainSpecs specFile) {
     app { bricPerlCluster @filename(clusterScript) iterationNo
                    @filename(randBrain) @filename(brainFile)
                    @filename(specFile); }
}

// Procedure to merge results based on statistical likelhoods
(brainClusterTable t) bricCentralize ( brainClusterTable bc[]) {
    app { bricCentralize @filenames(bc); }
}
```

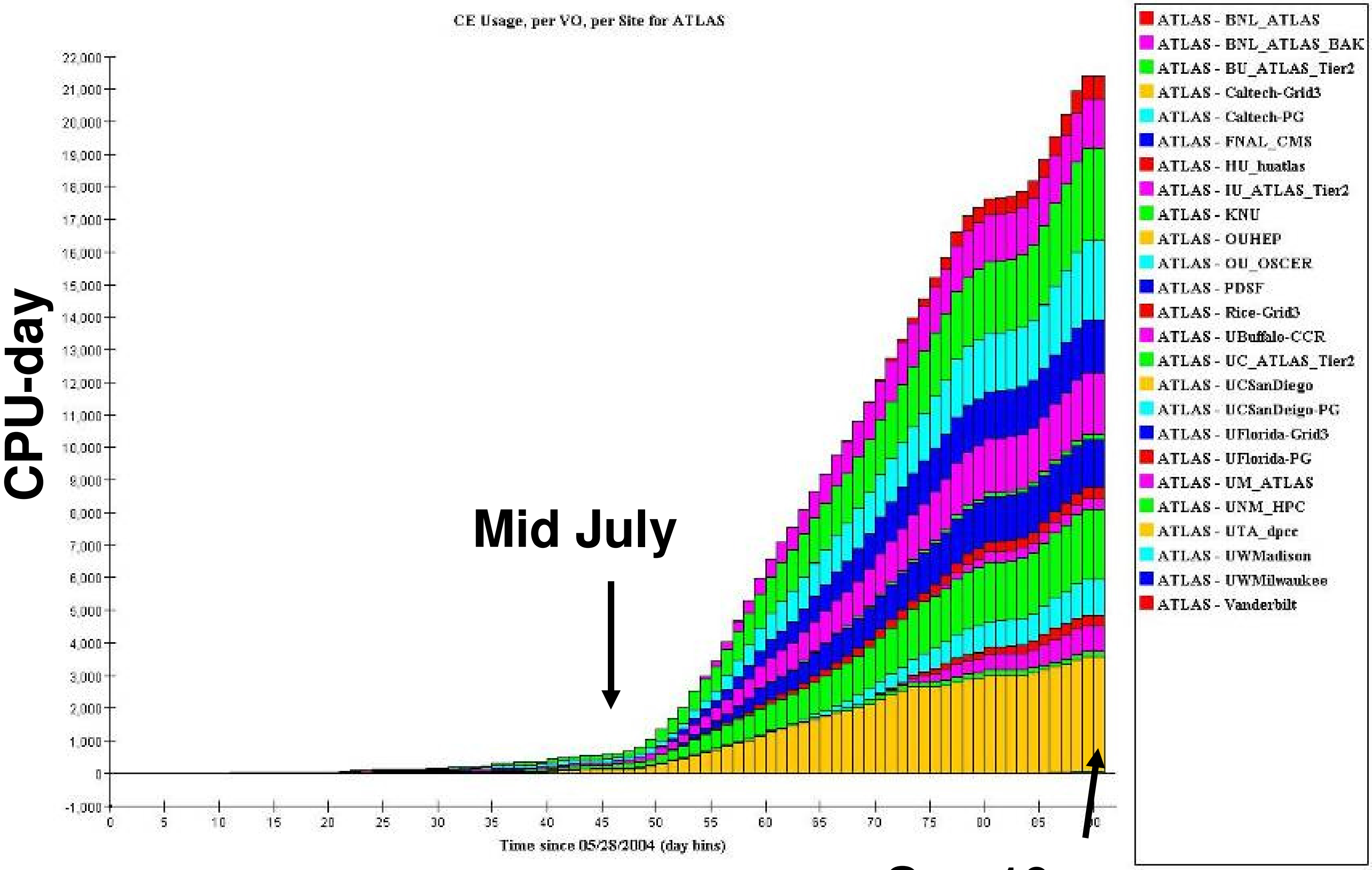
ACTIVAL: Dataset Iteration Procedures

```
// Procedure to iterate over the data collection

(brainClusters randCluster, brainDatasets dsetReturn) brain_cluster
  (fullBrainData brainFile, fullBrainSpecs specFile)
{
  int sequence[]=[1:2000];

  brainMeasurements          dataAll<fixed_mapper; file="obs.imit.all">;
  precomputedPermutations dataPerm<fixed_mapper; file="perm.matrix.11">;
  script                     randScript<fixed_mapper; file="script.obs.imit.tibi">;
  script                     clusterScript<fixed_mapper; file="surfclust.tibi">;
  brainDatasets              randBrains<simple_mapper; prefix="rand.brain.set">;

  foreach int i in sequence {
     randBrains.b[i] = bricRInvoke(randScript,i,dataAll,dataPerm);
     brainDataset rBrain=randBrains.b[i];
     (randCluster.c[i],dsetReturn.b[i]) =
        bricCluster(clusterScript,i,rBrain, brainFile,specFile);
  }
}
```

ACTIVAL: Main Program

```
// Declare datasets

fullBrainData        brainFile<fixed_mapper; file="colin_lh_mesh140_std.pial.asc">;
fullBrainSpecs       specFile<fixed_mapper; file="colin_lh_mesh140_std.spec">;

brainDatasets        randBrain<simple_mapper; prefix="rand.brain.set">;
brainClusters        randCluster<simple_mapper; prefix="Tmean.4mm.perm",
                         suffix="_ClstTable_r4.1_a2.0.1D">;
brainDatasets        dsetReturn<simple_mapper; prefix="Tmean.4mm.perm",
                         suffix="_Clustered_r4.1_a2.0.niml.dset">;
brainClusterTable    clusterThresholdsTable<fixed_mapper; file="thresholds.table">;
brainDataset         brainResult<fixed_mapper; file="brain.final.dset">;
brainDataset         origBrain<fixed_mapper; file="brain.permutation.1">;


// Main program – executes the entire application

(randCluster, dsetReturn) = brain_cluster(brainFile, specFile);

clusterThresholdsTable = bricCentralize (randCluster.c);

brainResult = makebrain(origBrain,clusterThresholdsTable,brainFile,specFile);
```

ATLAS Event Simulation



Mid July

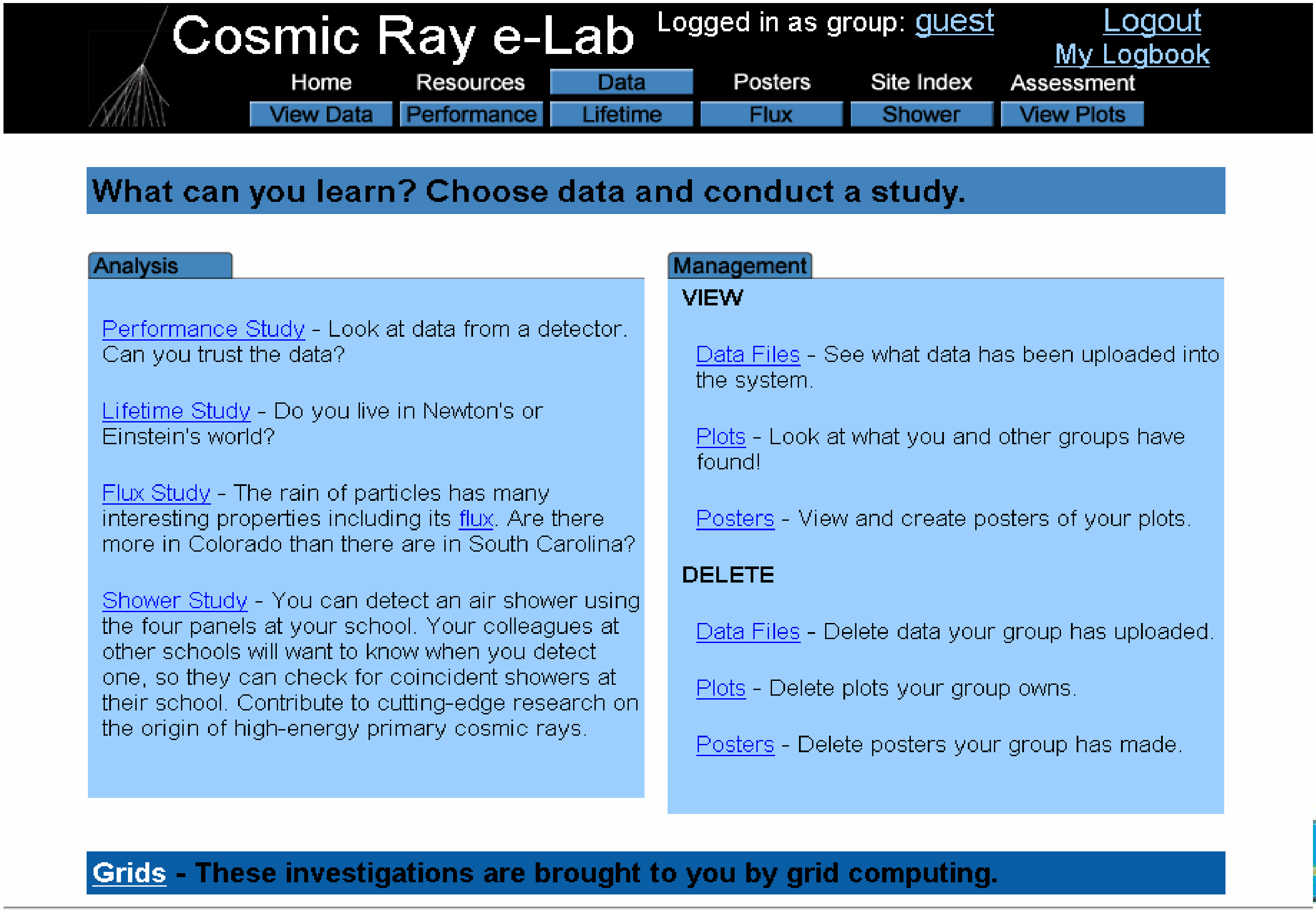
Sep 10

Sloan Digital Sky Survey

Sky region processed	450 sq deg
Num of sky fields	14,000
Num of procedure calls	5,000
Num of files	120,000
Num of Grid sites	4
Num of Processors used	500 total
Galaxy cluster identified	60,000

5days vs. 10 months for the whole dataset (7000 sq deg)

Web Interface



What can you learn? Choose data and conduct a study.

Analysis

Performance Study - Look at data from a detector. Can you trust the data?

Lifetime Study - Do you live in Newton's or Einstein's world?

Flux Study - The rain of particles has many interesting properties including its flux. Are there more in Colorado than there are in South Carolina?

Shower Study - You can detect an air shower using the four panels at your school. Your colleagues at other schools will want to know when you detect one, so they can check for coincident showers at their school. Contribute to cutting-edge research on the origin of high-energy primary cosmic rays.

Management

VIEW

Data Files - See what data has been uploaded into the system.

Plots - Look at what you and other groups have found!

Posters - View and create posters of your plots.

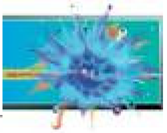
DELETE

Data Files - Delete data your group has uploaded.

Plots - Delete plots your group owns.

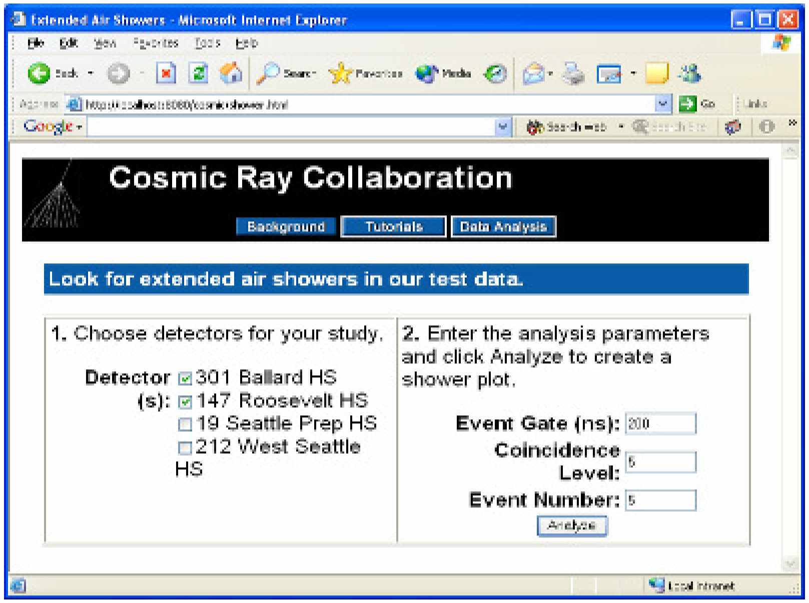
Posters - Delete posters your group has made.

Grids - These investigations are brought to you by grid computing.



Collaboration with Marge Bardeen, Tom Jordan, Liz Quigg, Eric Gilbert, Paul Nepywoda, Fermilab [CCGRID05] [FGCS05]

Sample Program



Cosmic Ray Collaboration

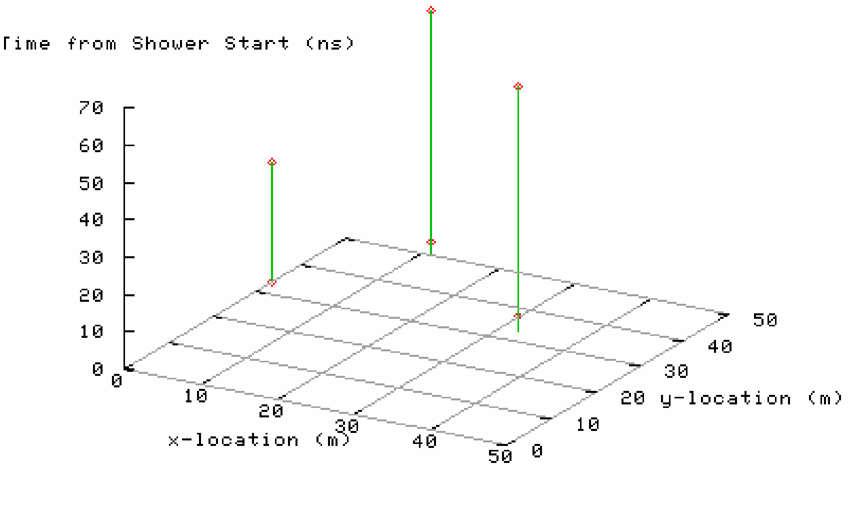
Look for extended air showers in our test data.

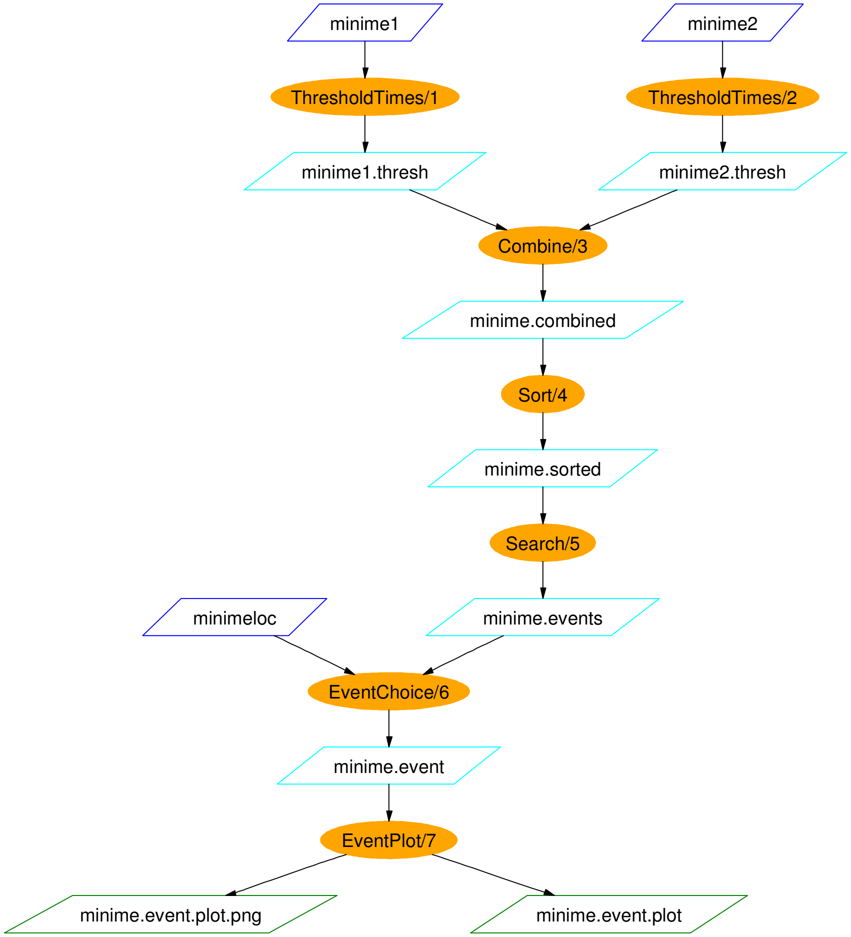
1. Choose detectors for your study.

Detector (s): ☑ 301 Ballard HS ☑ 147 Roosevelt HS □ 19 Seattle Prep HS □ 212 West Seattle HS

2. Enter the analysis parameters and click Analyze to create a shower plot.

Event Gate (ns):	200
Coincidence Level:	5
Event Number:	5





minime1

ThresholdTimes/1

minime1.thresh

minime2

ThresholdTimes/2

minime2.thresh

Combine/3

minime.combined

Sort/4

minime.sorted

Search/5

minime.events

minimeloc

EventChoice/6

minime.event

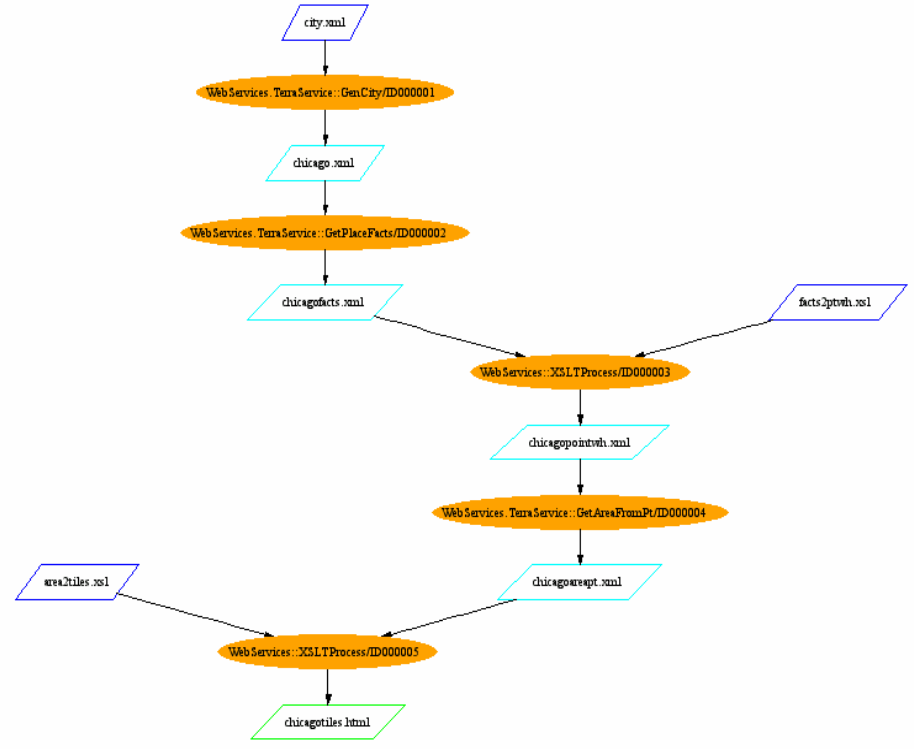
EventPlot/7

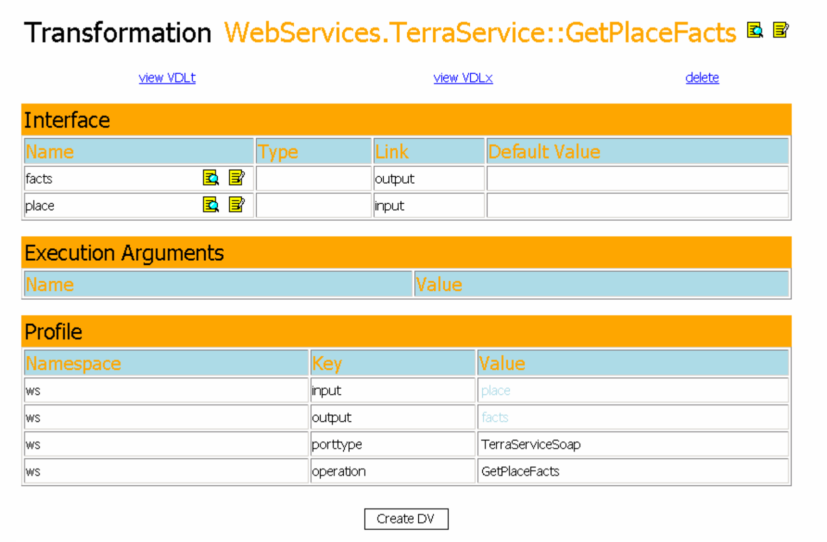
minime.event.plot.png

minime.event.plot

Web Services

- WS described/imported as procedures
- Dynamic invocation
- XSLT as glue


city.xml
WebServices.TerraService::GenCity/ID000001
chicago.xml
WebServices.TerraService::GetPlaceFacts/ID000002
chicagofacts.xml
facts2ptwh.xsl
WebServices::XSLTProcess/ID000003
chicagopointwh.xml
WebServices.TerraService::GetAreaFromPt/ID000004
area2tiles.xsl
chicagoareapt.xml
WebServices::XSLTProcess/ID000005
chicagotiles.html


Transformation WebServices.TerraService::GetPlaceFacts

view VDLt view VDLx delete

Interface

Name	Type	Link	Default Value
facts		output	
place		input	

Execution Arguments

Name	Value

Profile

Namespace	Key	Value
ws	input	place
ws	output	facts
ws	porttype	TerraServiceSoap
ws	operation	GetPlaceFacts