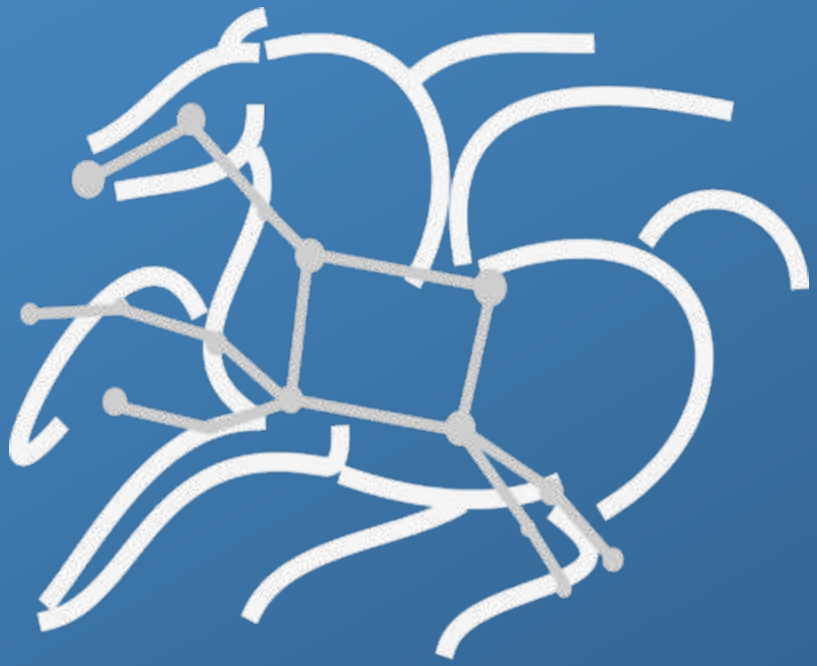
Automating Real-time Seismic Analysis

Through Streaming and High Throughput Workflows



Rafael Ferreira da Silva, Ph.D.

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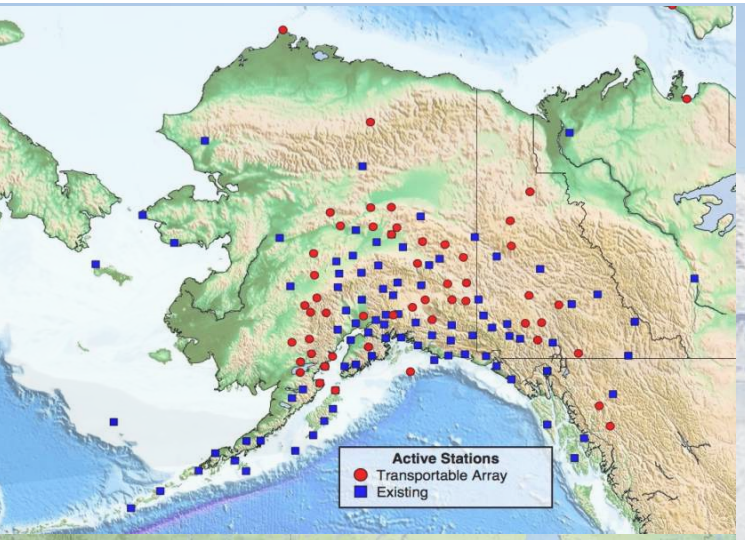
Information Sciences Institute

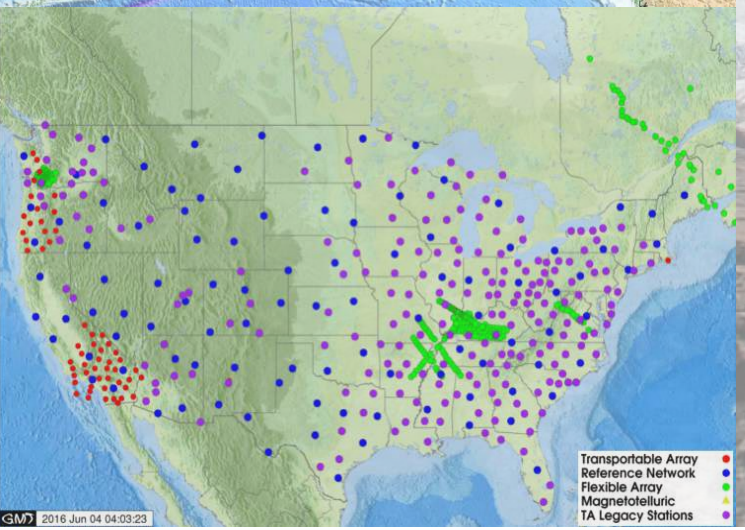
http://pegasus.isi.edu

Do we need seismic analysis?

USArray

A continental-scale Seismic Observatory

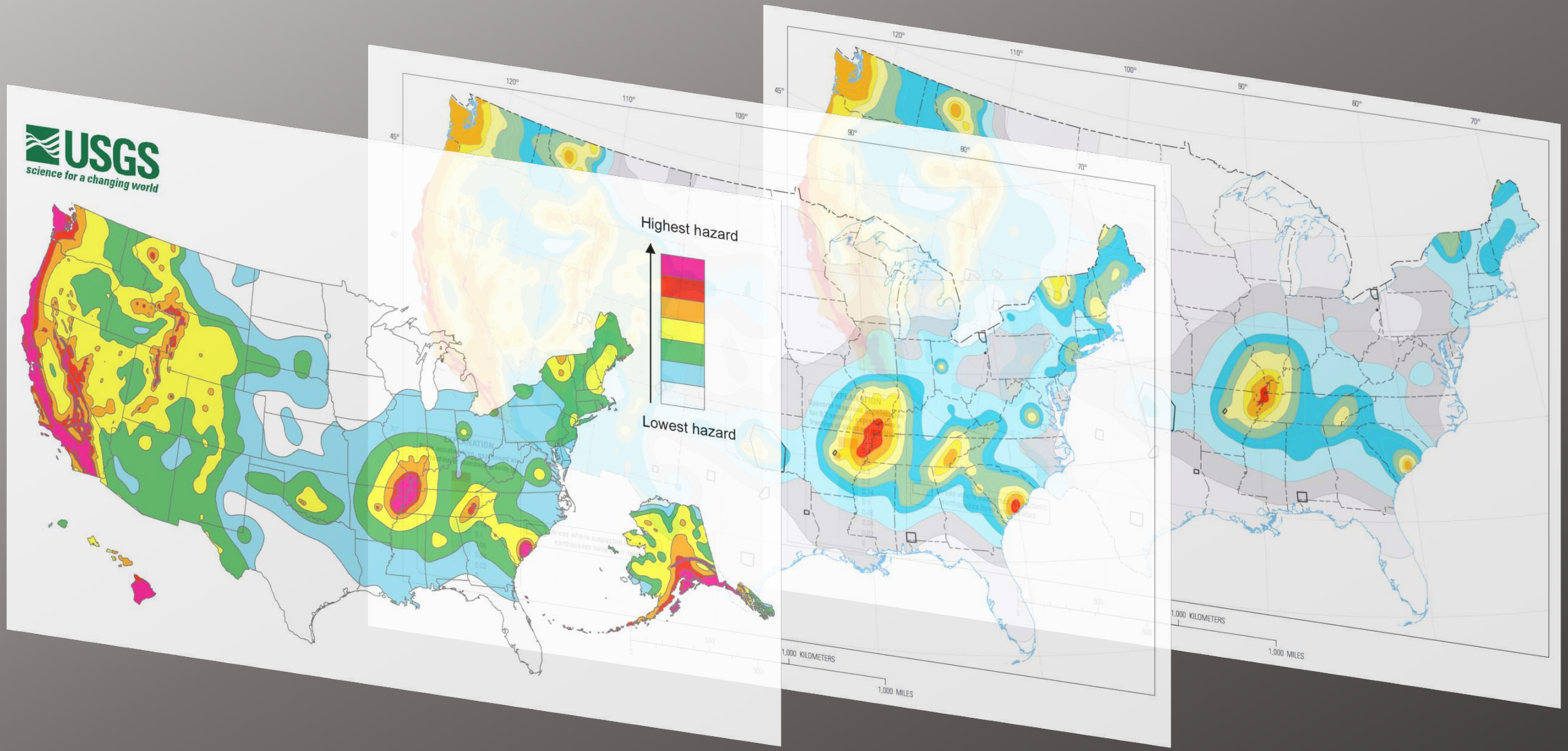




US Array TA (IRIS Service)
836 stations
394 stations have online data available

http://ds.iris.edu/ds/nodes/dmc/earthscope/usarray/_US-TA-operational/

The development of reliable risk assessment methods for these hazards requires real-time analysis of seismic data

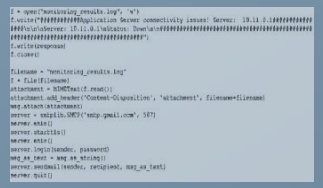


So, how to efficiently process these data?

Experiment Timeline

Scientific Problem

Earth Science, Astronomy, Neuroinformatics, Bioinformatics, etc.



Computational Scripts

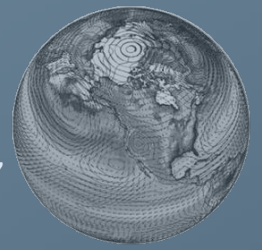
Shell scripts, Python, Matlab, etc.

Distributed Computing

Clusters, HPC, Cloud, Grid, etc.

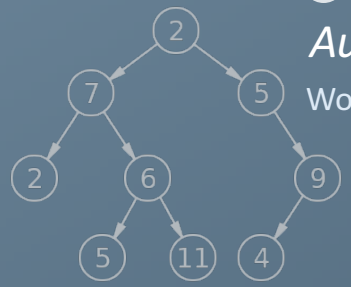
Scientific Result

Models, Quality Control, Image Analysis, etc.



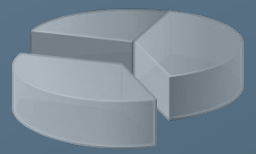
$$U\frac{\mathrm{d}^2}{\mathrm{d}x^2}U^{-1}g = \left(U\frac{\mathrm{d}}{\mathrm{d}x}U^{-1}\right)\times\left(U\frac{\mathrm{d}}{\mathrm{d}x}U^{-1}\right)g$$
$$= \frac{\mathrm{d}}{\mathrm{d}\psi}\left[g'\psi' + \frac{1}{2}g\frac{\psi''}{\psi'}\right]\cdot\psi' + \frac{1}{2}\left[g'\psi' + \frac{1}{2}g\frac{\psi''}{\psi'}\right]\times\frac{\psi''}{\psi'}$$
$$= g''\psi'^2 + 2g'\psi'' + \frac{1}{2}g\times\left[\frac{\psi'''}{\psi'} + \frac{\psi''^2}{\psi'^2}\right]$$

Analytical Solution



Automation

Workflows, MapReduce, etc.



Monitoring and Debug

Fault-tolerance, Provenance, etc.

What is involved in an experiment execution?

Why Scientific Workflows?

Automates complex, multi-stage processing pipelines

Enables parallel, distributed computations

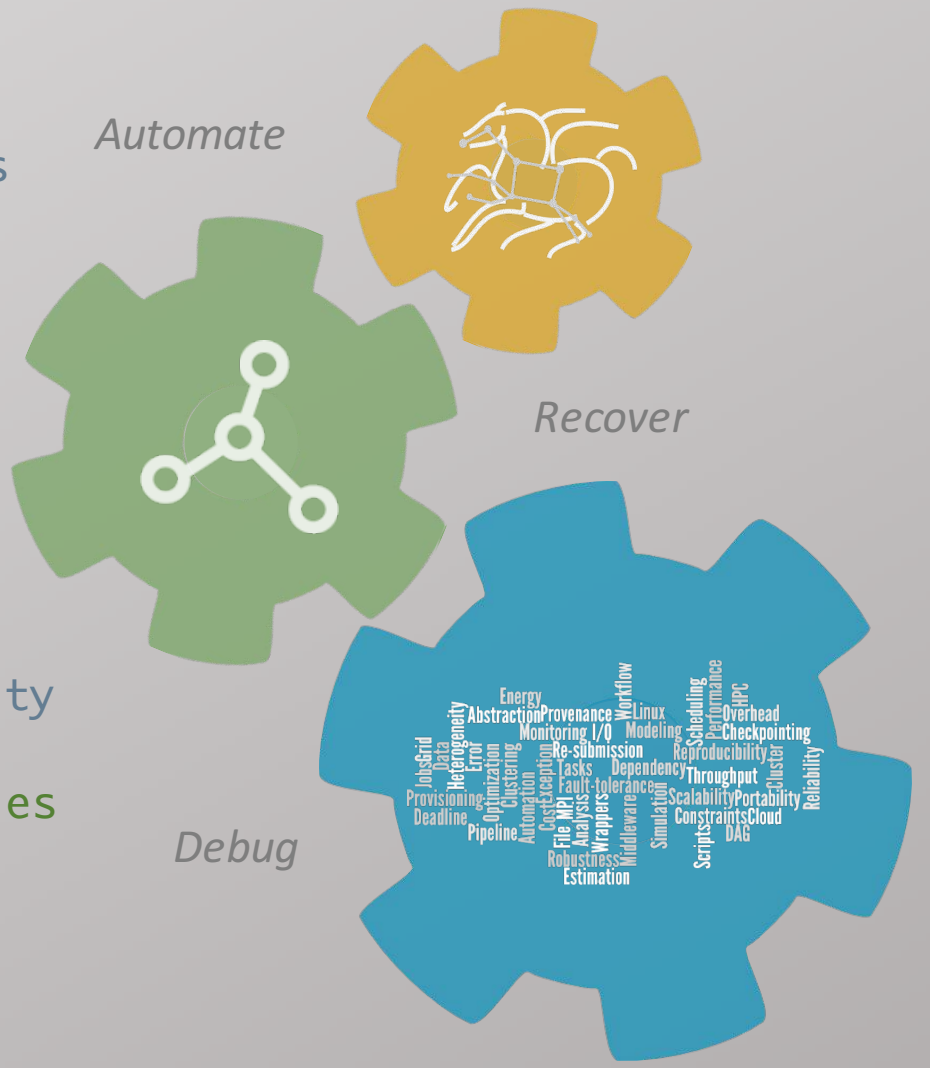
Automatically executes data transfers

Reusable, aids reproducibility

Records how data was produced (provenance)

Handles failures with to provide reliability

Keeps track of data and files



Taking a closer look into a workflow…

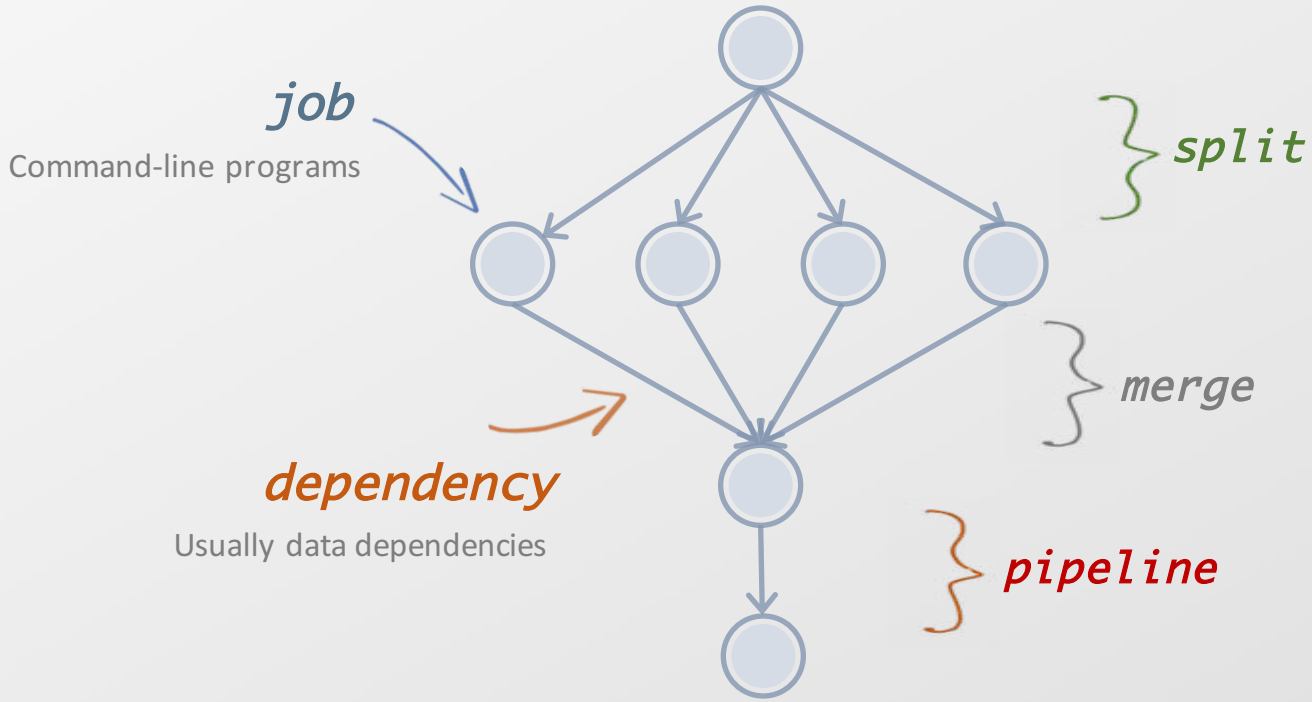
abstract workflow

executable workflow

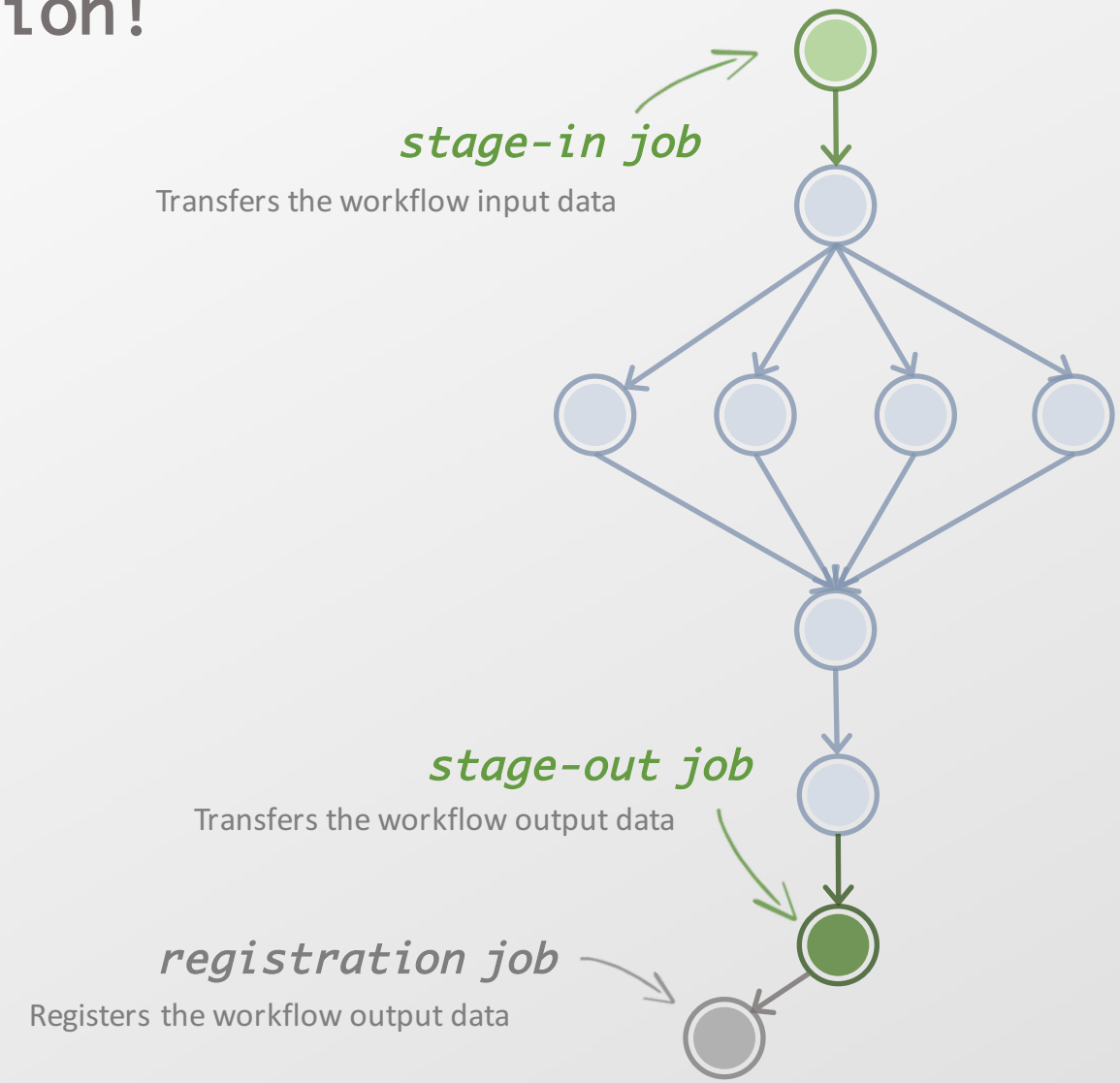
optimizations

storage constraints

directed-acyclic graphs



From the abstraction to execution!



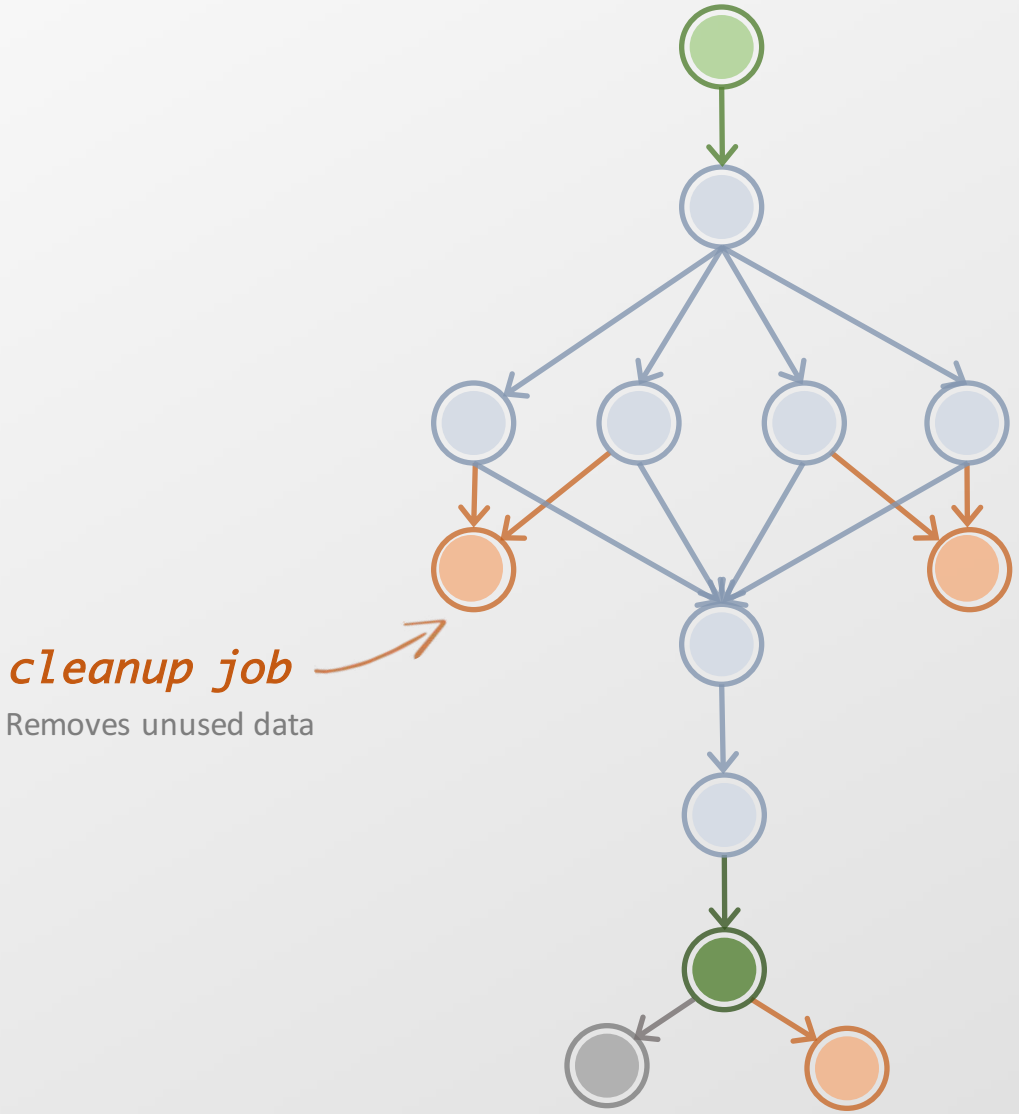
Optimizing storage usage…

abstract workflow

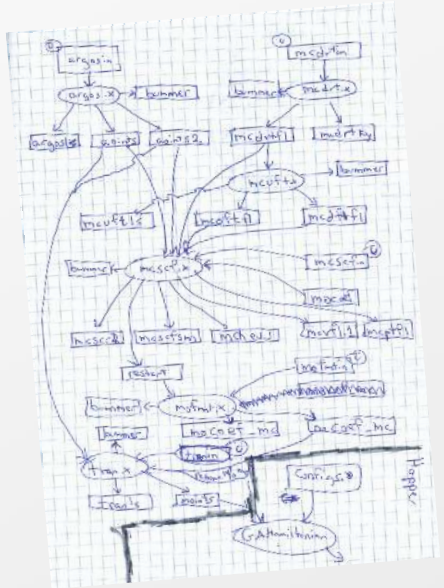
executable workflow

optimizations

storage constraints

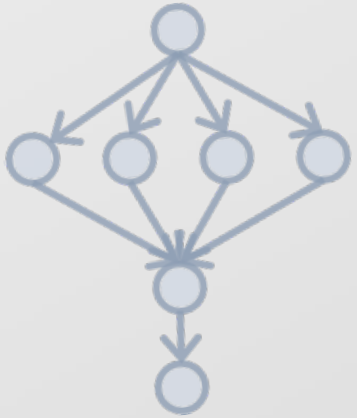


Workflow systems provide tools to generate the abstract workflow

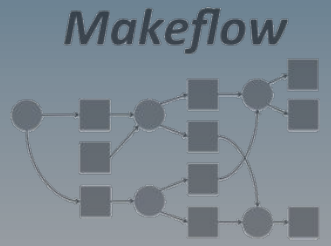


python™ R Java perl

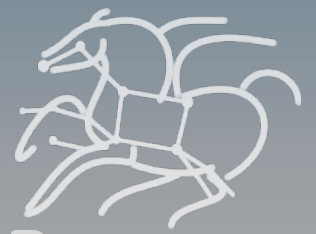
```
dax = ADAG("test_dax")
firstJob = Job(name="first_job")
firstInputFile = File("input.txt")
firstOutputFile = File("tmp.txt")
firstJob.addArgument("input=input.txt", "output=tmp.txt")
firstJob.uses(firstInputFile, link=Link.INPUT)
firstJob.uses(firstOutputFile, link=Link.OUTPUT)
dax.addJob(firstJob)
for i in range(0, 5):
    simulJob = Job(id="%s" % (i+1), name="simul_job")
    simulInputFile = File("tmp.txt")
    simulOutputFile = File("output.%d.dat" % i)
    simulJob.addArgument("parameter=%d" % i, "input=tmp.txt",
        output=%s" % simulOutputFile.getName())
    simulJob.uses(simulInputFile, link=Link.INPUT)
    simulJob.uses(simulOutputFile, line=Link.OUTPUT)
dax.addJob(simulJob)
dax.depends(parent=firstJob, child=simulJob)
fp = open("test.dax", "w")
dax.writeXML(fp)
fp.close()
```



abstract workflow



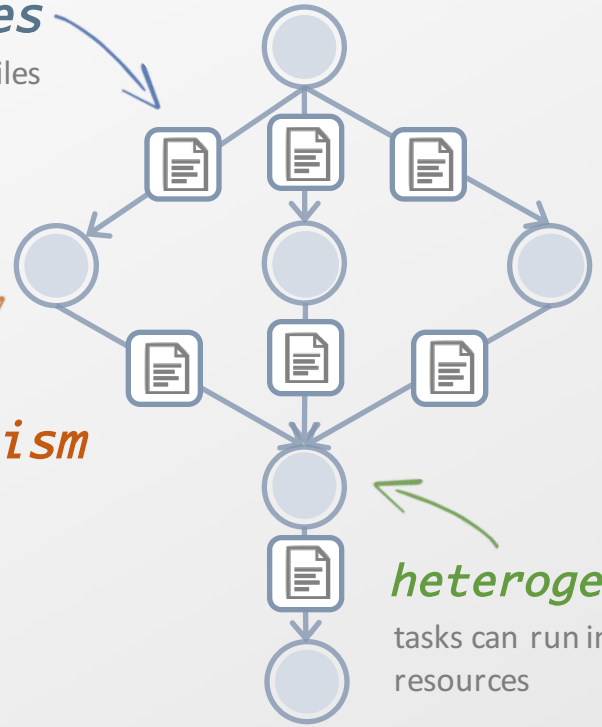
Nimrod



Which Workflow Management System?

…and which model to use?

task-oriented



files

data transfers via files

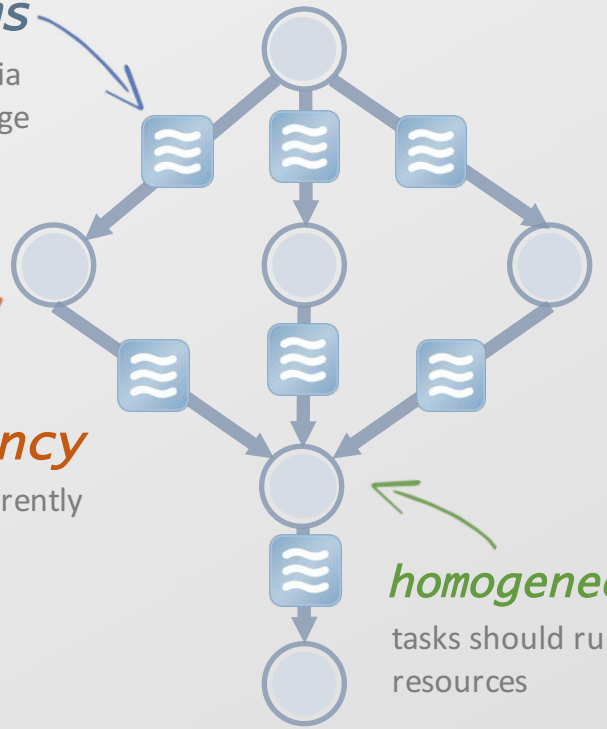
parallelism

no concurrency

heterogeneous execution

tasks can run in heterogeneous resources

stream-based



streams

data transfers via memory or message

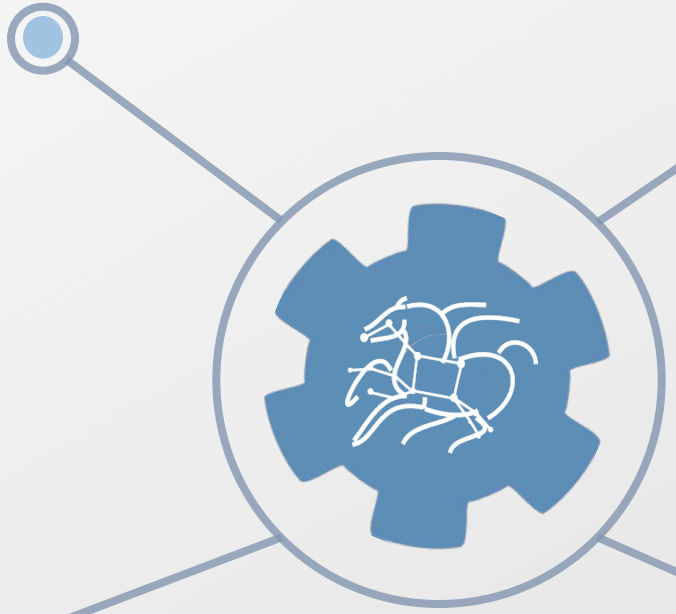
concurrency

tasks run concurrently

homogeneous execution

tasks should run in homogeneous resources

What does Pegasus provide?



Automation

Automates pipeline executions
Parallel, distributed computations
Automatically executes data transfers
Heterogeneous resources
Task-oriented model
Application is seen as a black box

Debug

Workflow execution and job performance metrics
Set of debugging tools to unveil issues
Real-time monitoring, graphs, provenance

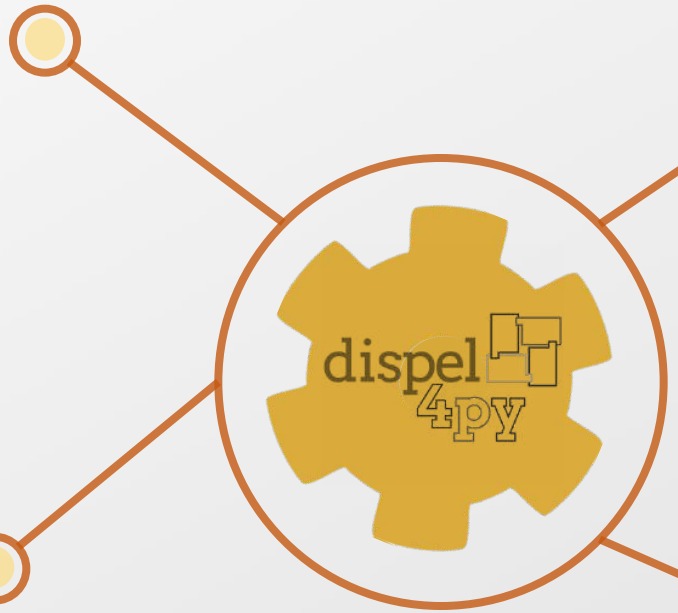
Recovery

Job failure detection
Checkpoint Files
Job Retry
Rescue DAGs

Optimization

Job clustering
Data cleanup

…and dispel4py?



Automation

Automates pipeline executions
Concurrent, distributed computations
Stream-based model

Workflow Composition

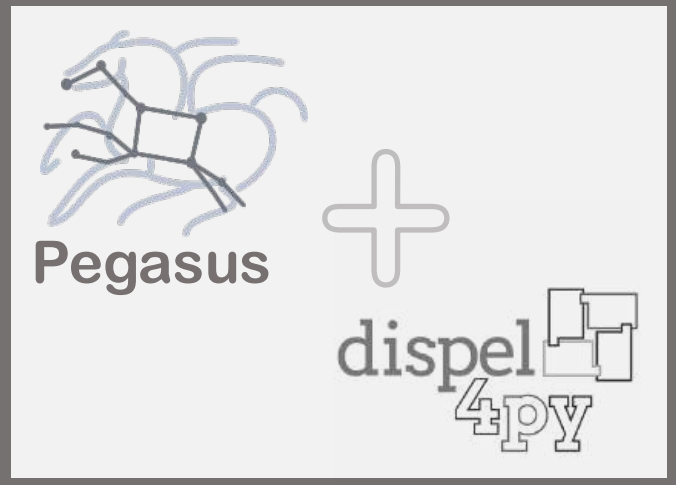
Python Library
Grouping (all-to-all, all-to-one, one-to-all)

Mapping

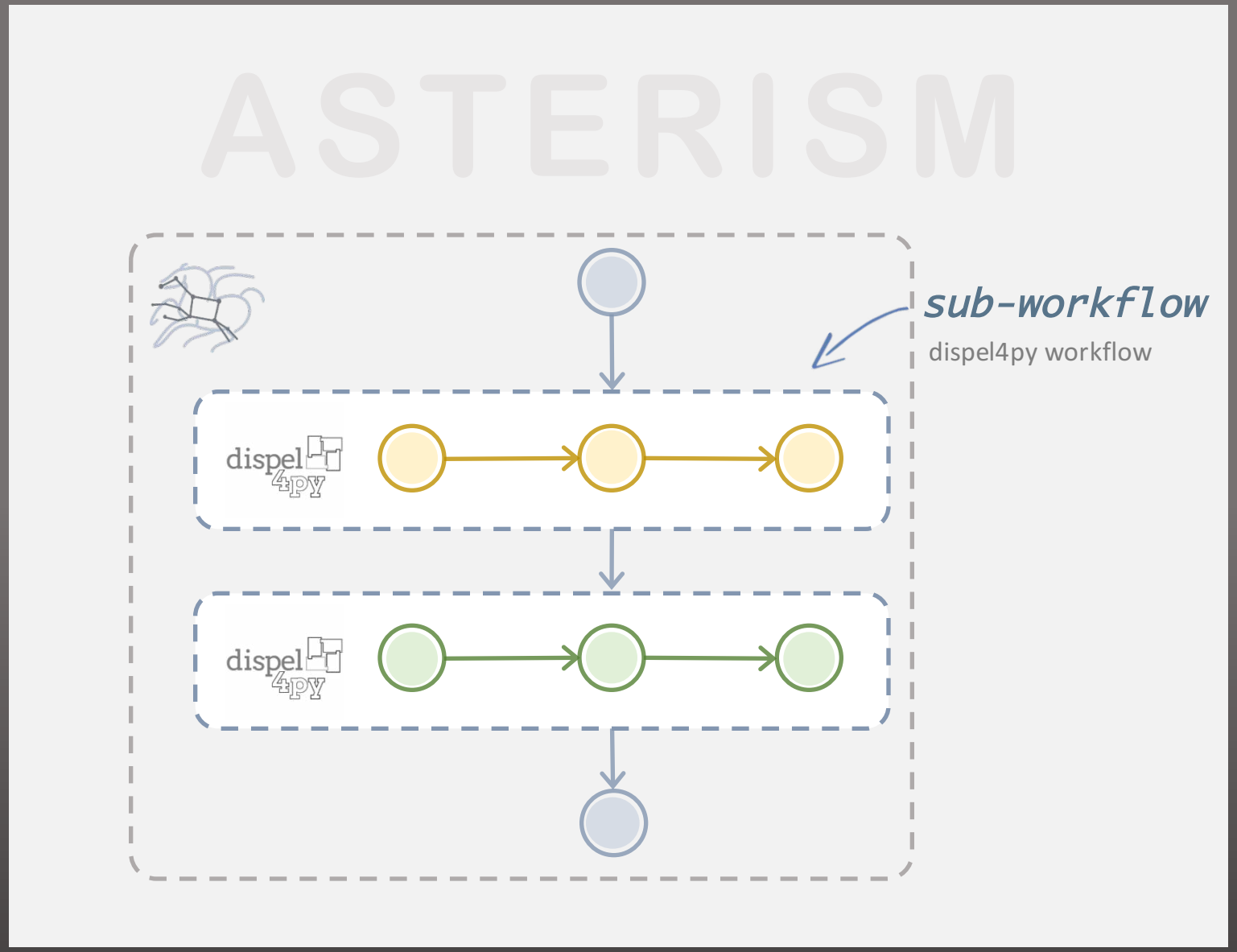
Sequential
Multiprocessing (shared memory)
Distributed memory, message passing (MPI)
Distributed Real-time (Apache Storm)
Apache Spark (Prototype)

Optimization

Multiple streams (in/out)
Avoids I/O (shared memory
or message passing)



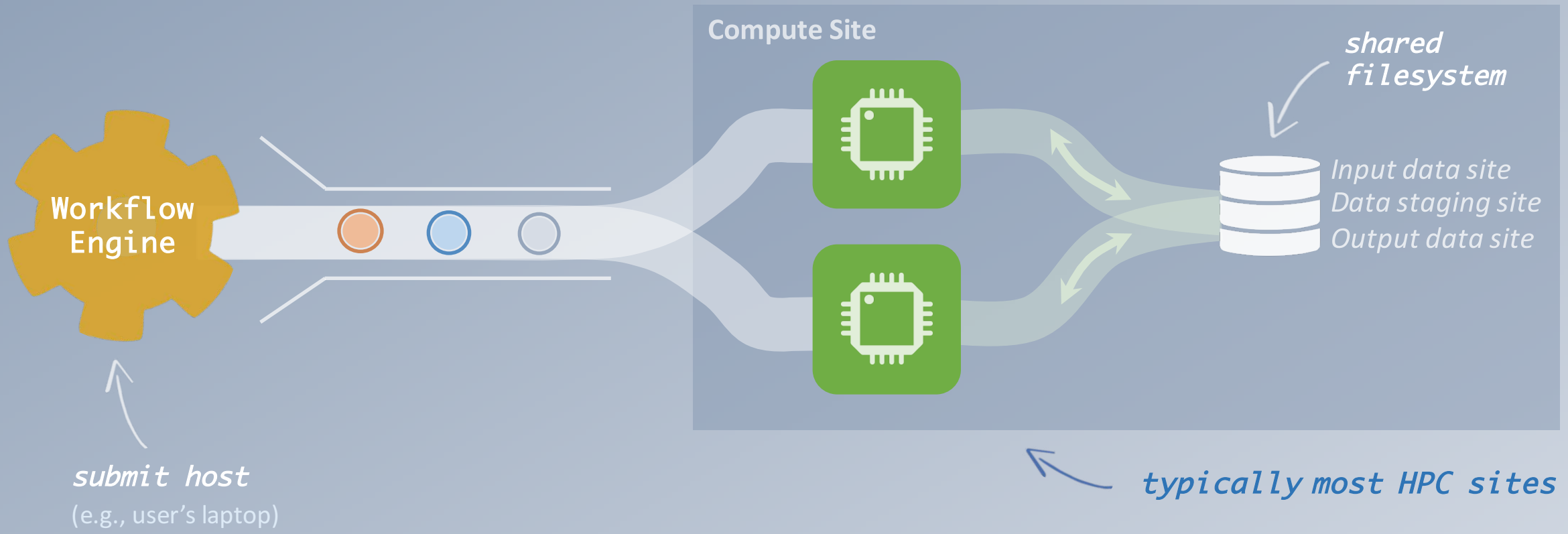
Asterism greatly simplifies the effort required to develop data-intensive applications that run across multiple heterogeneous resources distributed in the wide area



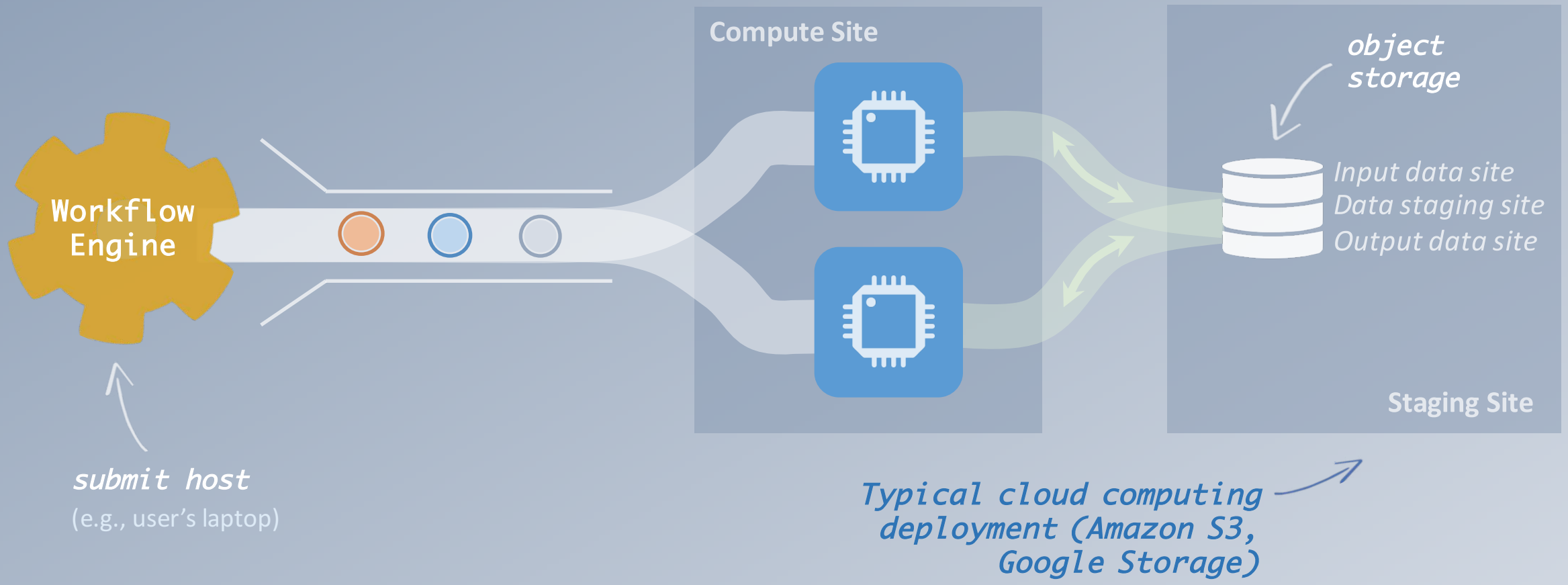
Where to run scientific workflows?

High Performance Computing

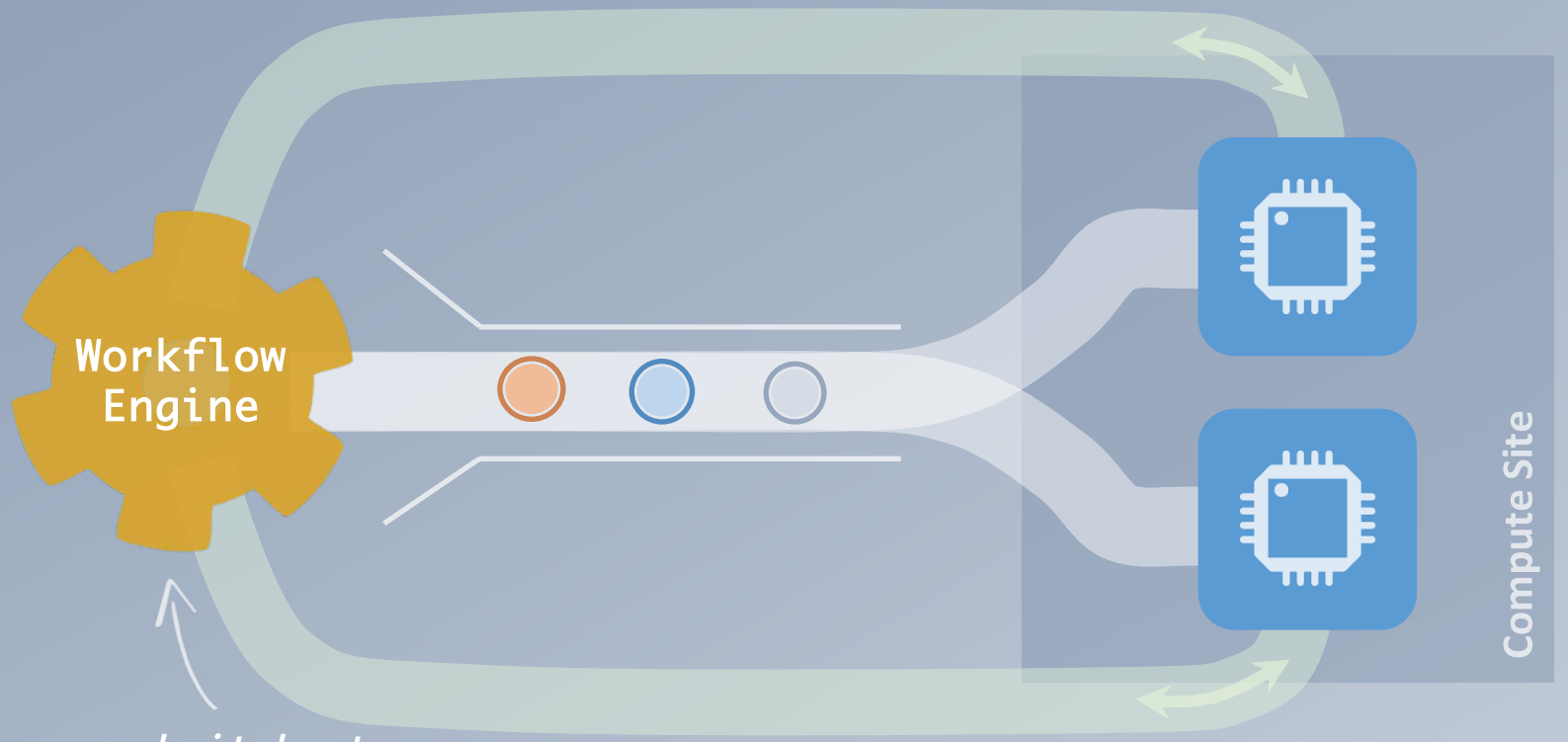
There are several possible configurations…



High-scalable object storages



local data management



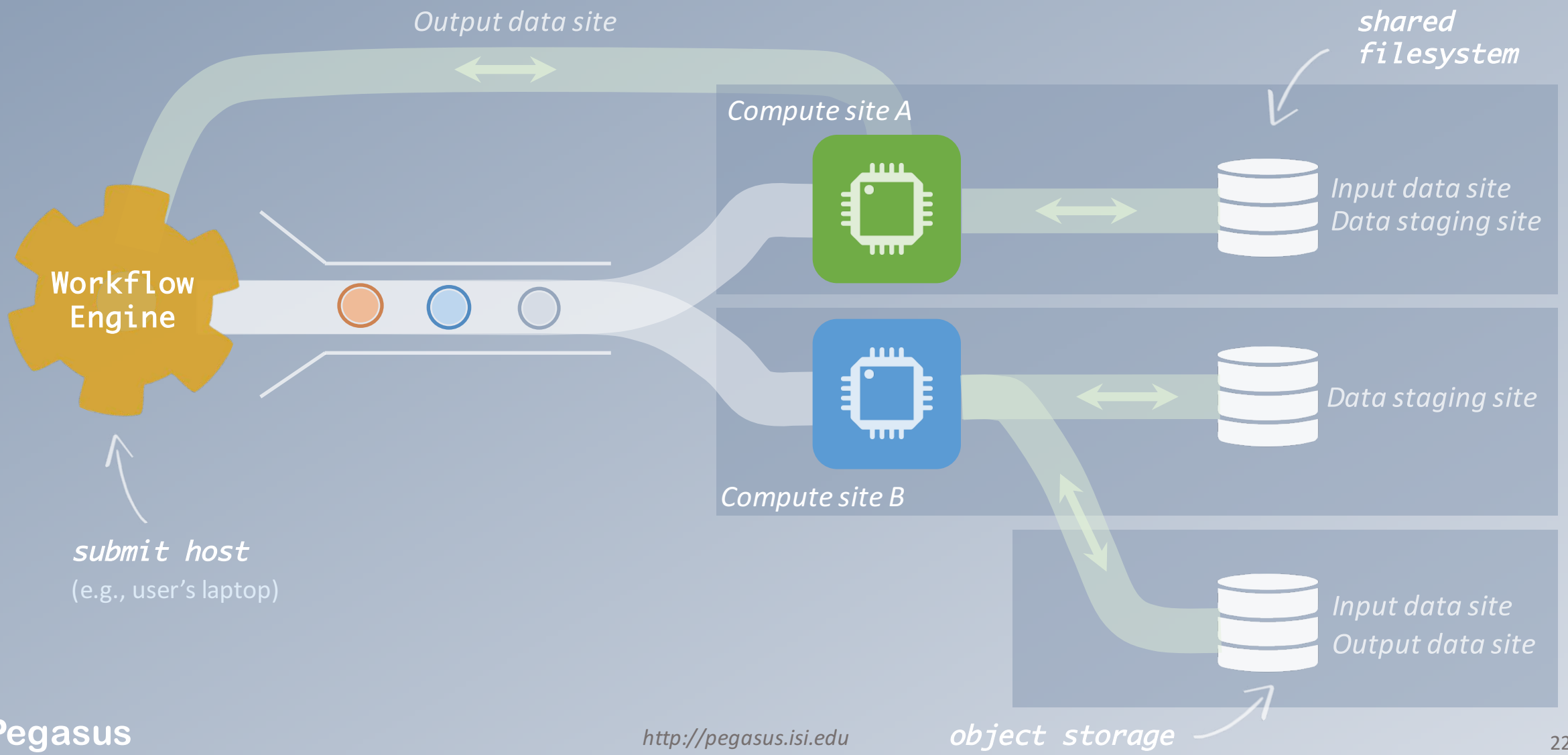
Typical OSG sites

Open Science Grid

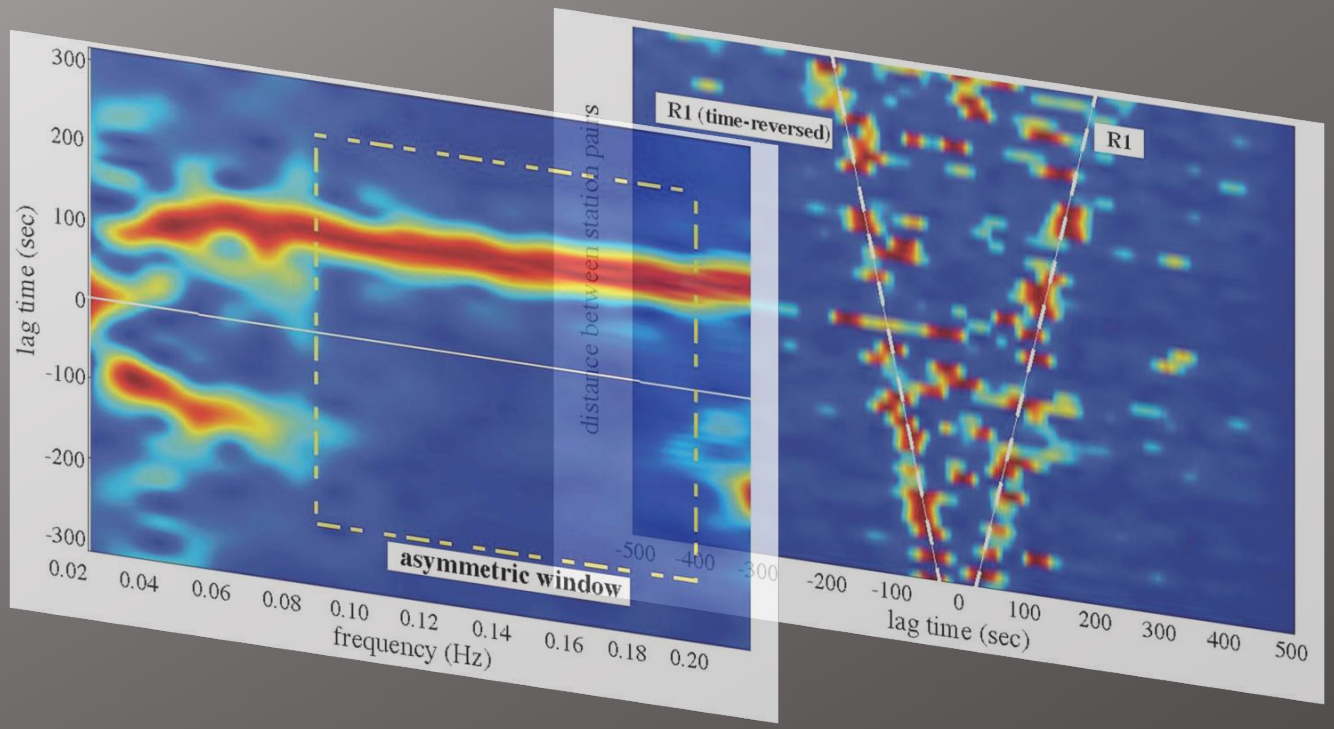
submit host

(e.g., user's laptop)

And yes… you can mix everything!



How do we use Asterism to automate seismic analysis?



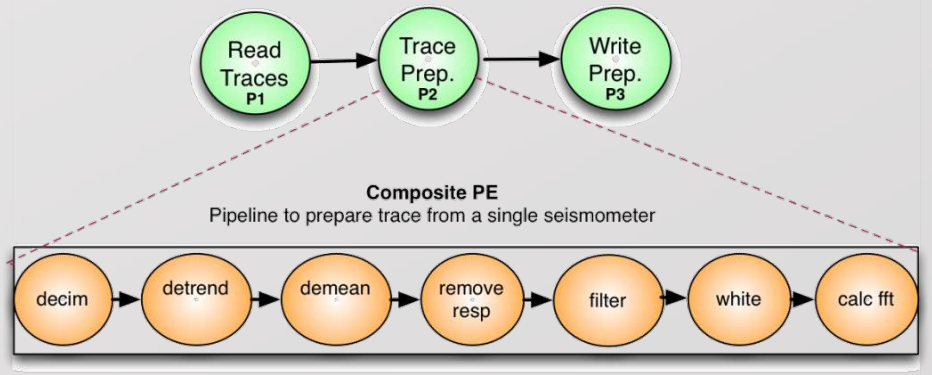
Seismic Ambient Noise Cross-Correlation

Preprocesses and cross-correlates traces (sequences of measurements of acceleration in three dimensions) from multiple seismic stations (IRIS database)

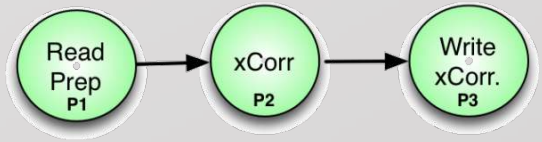
Phase 1: data preparation using statistics for extracting information from the noise

Phase 2: compute correlation, identifying the time for signals to travel between stations. Infers properties of the intervening rock

ObsPy
A Python Framework for Seismology

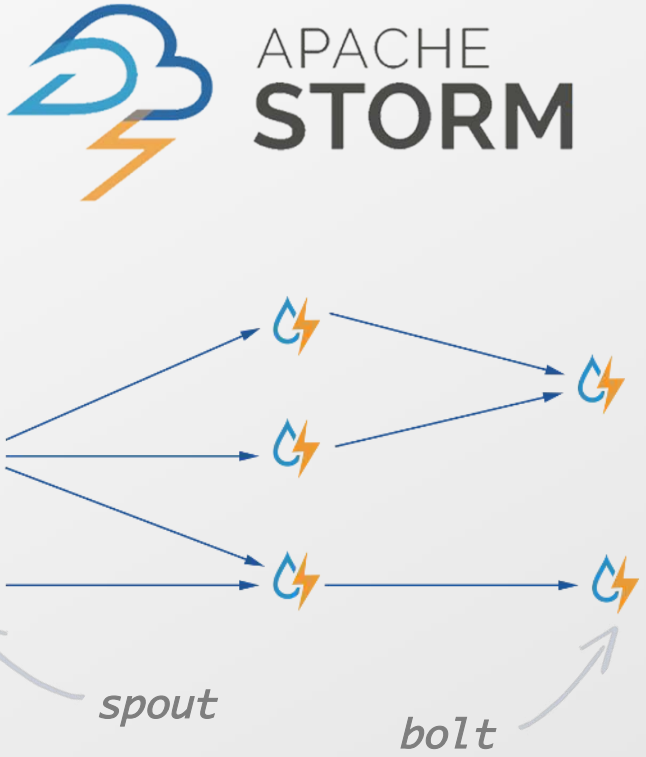


Phase 1 (pre-process)



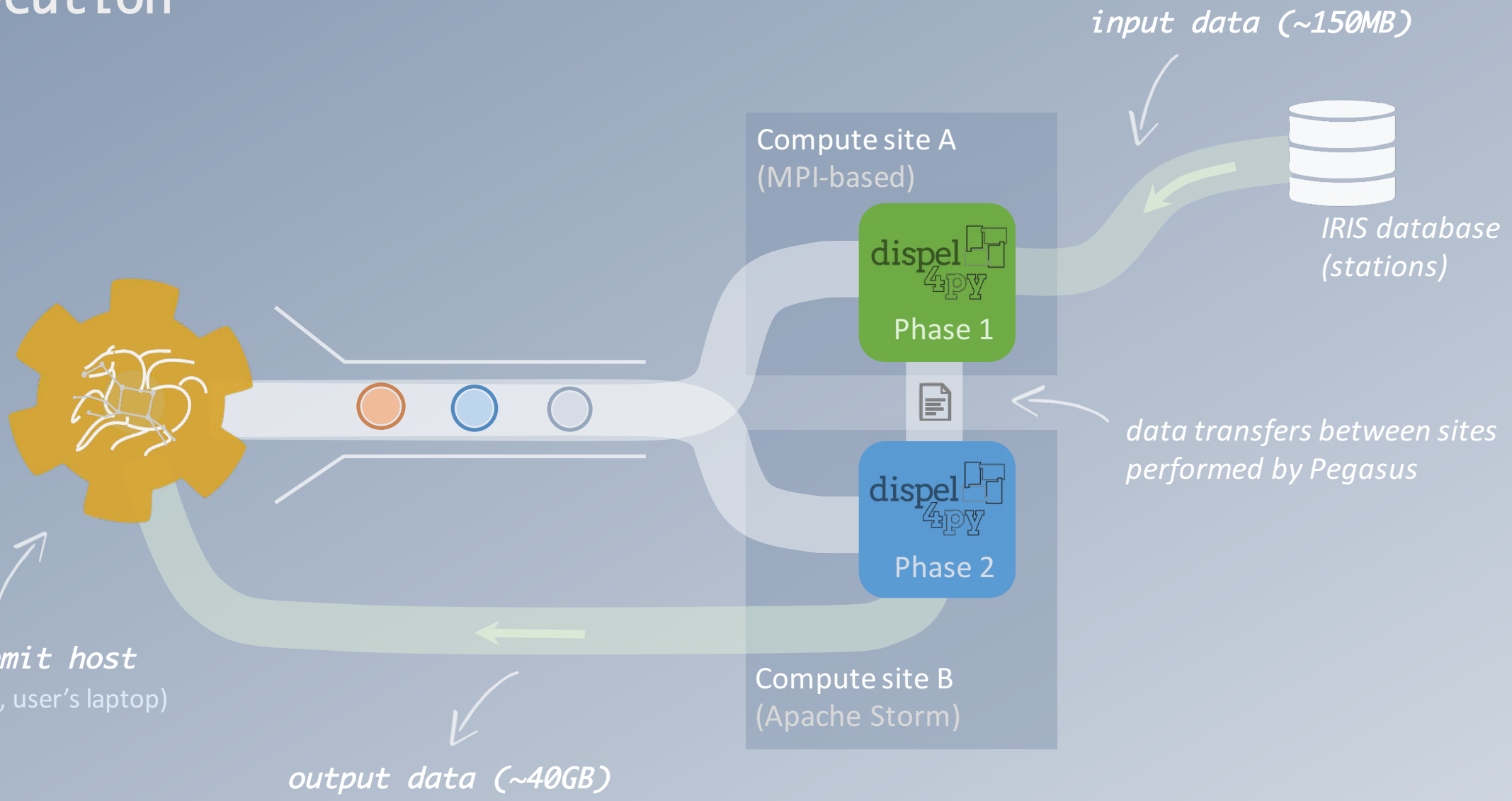
Phase 2 (cross-correlation)

Seismic Ambient Noise Cross-Correlation WORKFLOW



- Distributed computation framework for event stream processing
- Designed for massive scalability, supports fault-tolerance with a “fail fast, auto restart” approach to processes
- Rich array of available spouts specialized for receiving data from all types of sources
- Hadoop of real-time processing, very scalable

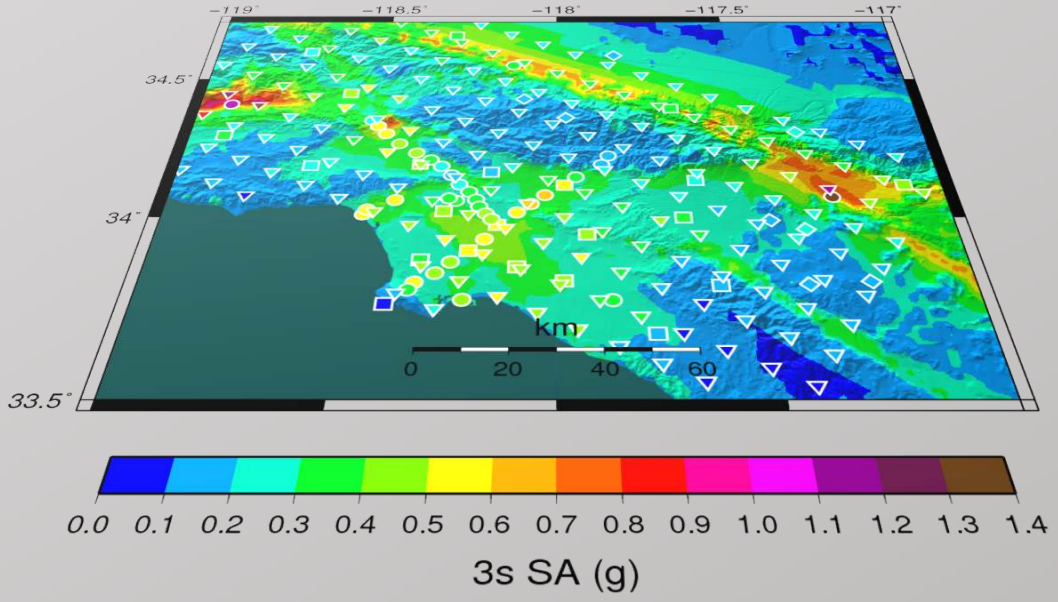
Seismic workflow execution

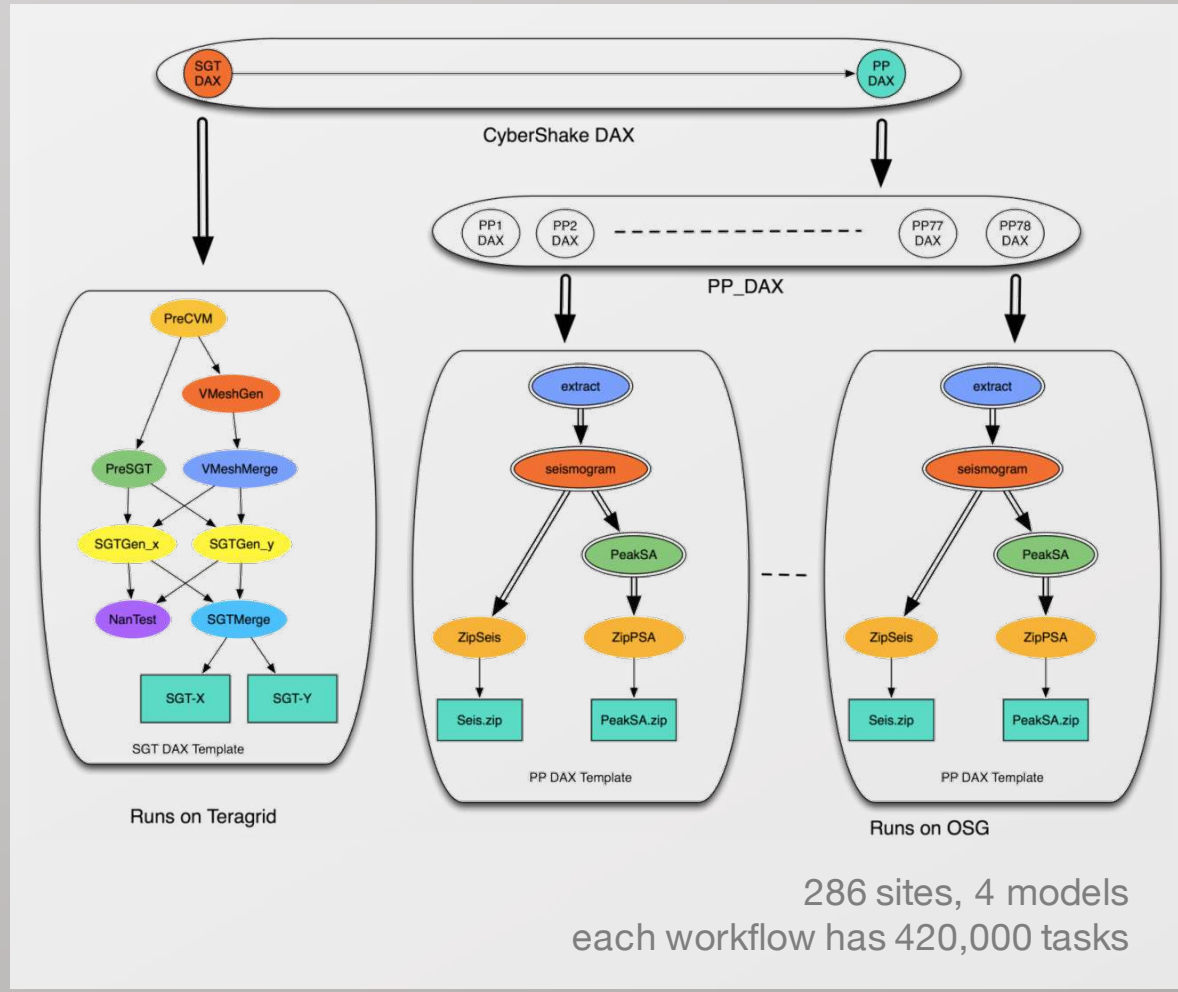


Southern California Earthquake Center's CyberShake

Builders ask seismologists: What will the peak ground motion be at my new building in the next 50 years?

Seismologists answer this question using Probabilistic Seismic Hazard Analysis (PSHA)





286 sites, 4 models
each workflow has 420,000 tasks

A few more workflow features…

Performance, why not improve it?

workflow restructuring

workflow reduction

hierarchical workflows

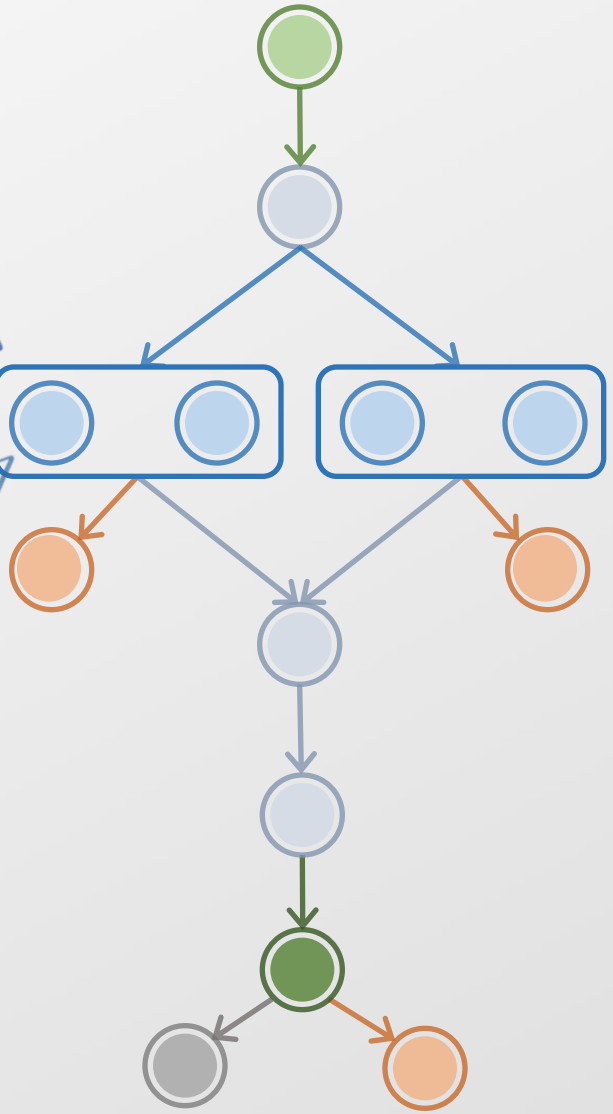
pegasus-mpi-cluster

clustered job

Groups small jobs together to improve performance

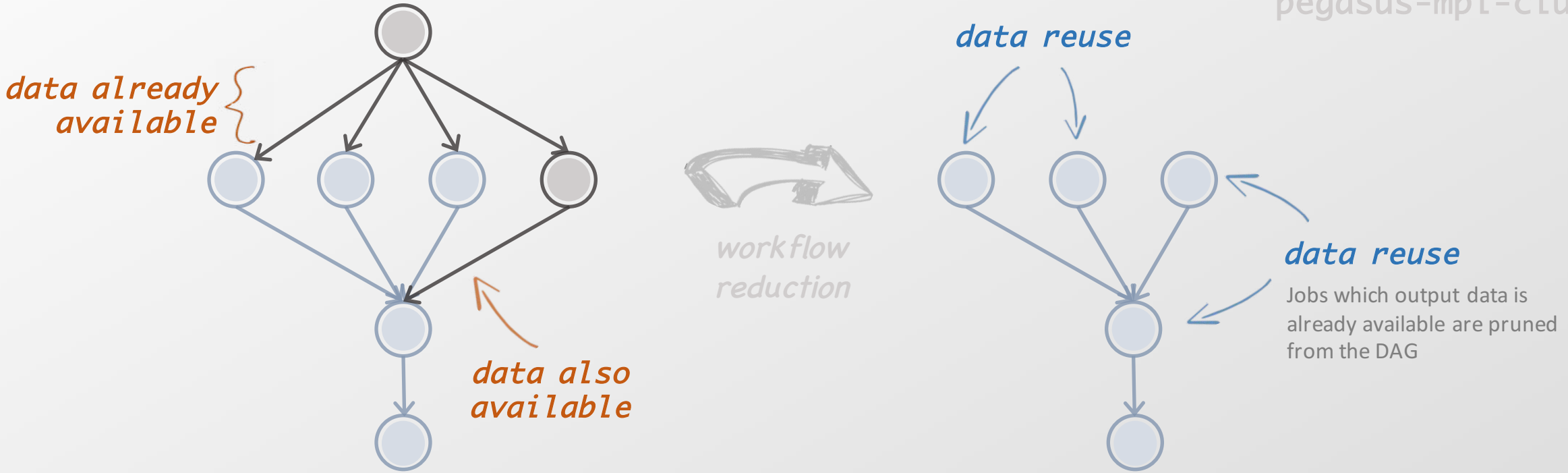
task

small granularity

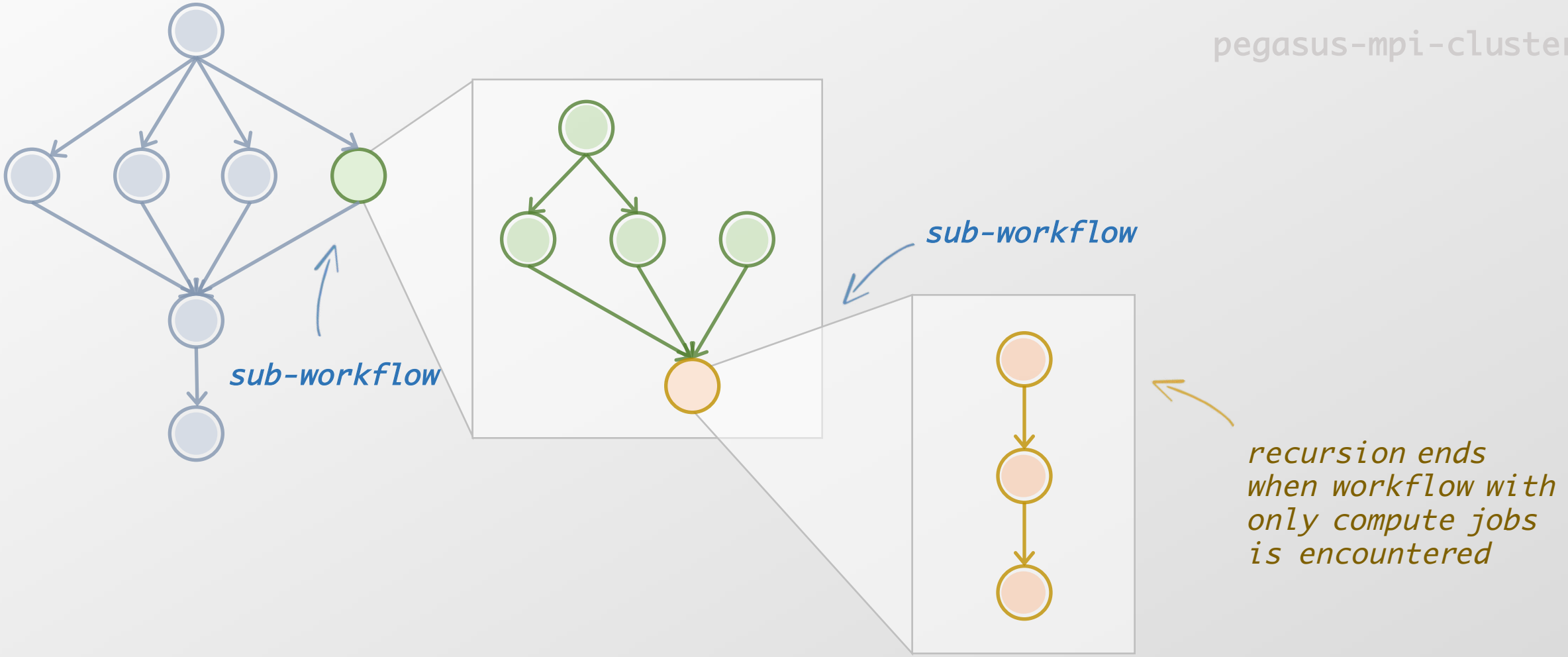


http://pegasus.isi.edu

What about **data reuse**?



Handling large-scale workflows



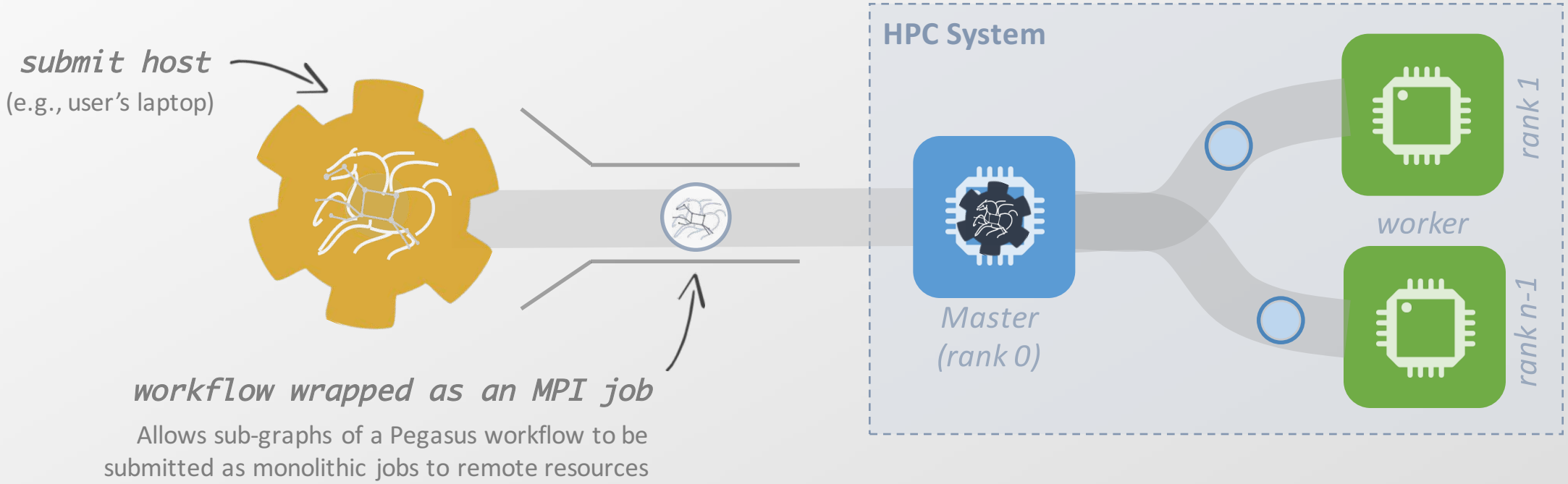
Running fine-grained workflows on HPC systems…

workflow restructuring

workflow reduction

hierarchical workflows

pegasus-mpi-cluster



workflow wrapped as an MPI job

Allows sub-graphs of a Pegasus workflow to be submitted as monolithic jobs to remote resources

Pegasus est. 2001

Automate, recover, and debug scientific computations.

Get Started

Pegasus Website

http://pegasus.isi.edu

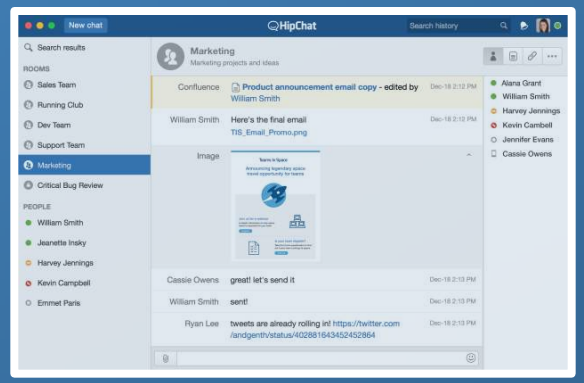
Users Mailing List

pegasus-users@isi.edu

Support

pegasus-support@isi.edu

HipChat



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Through Streaming and High Throughput Workflows

Thank You

Questions?

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School of Engineering
Information Sciences Institute

Meet our team

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