European and Chinese Cooperation on Grid

Grid Workflows
Current Stage and Future Directions

Institute of Computer Science, University of Innsbruck, Austria

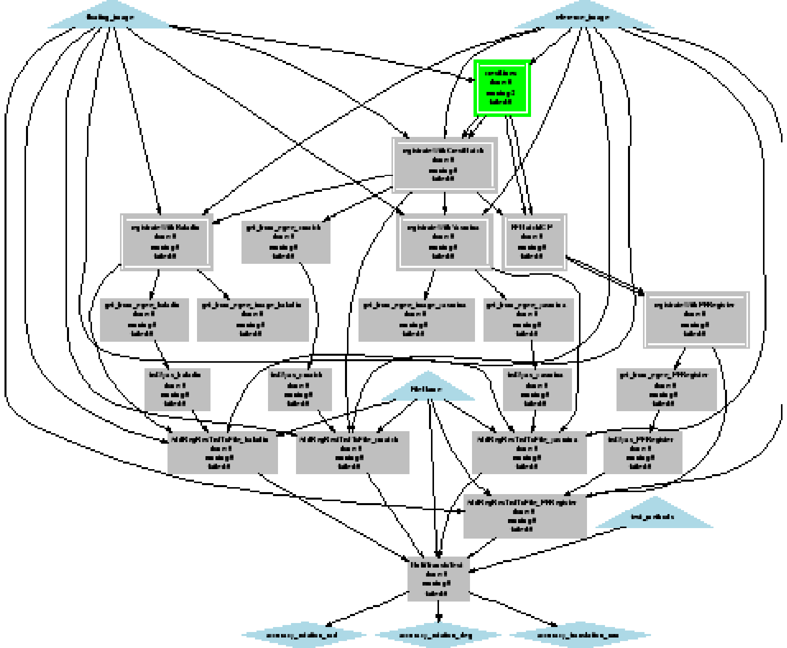
Radu Prodan

radu@dps.uibk.ac.at

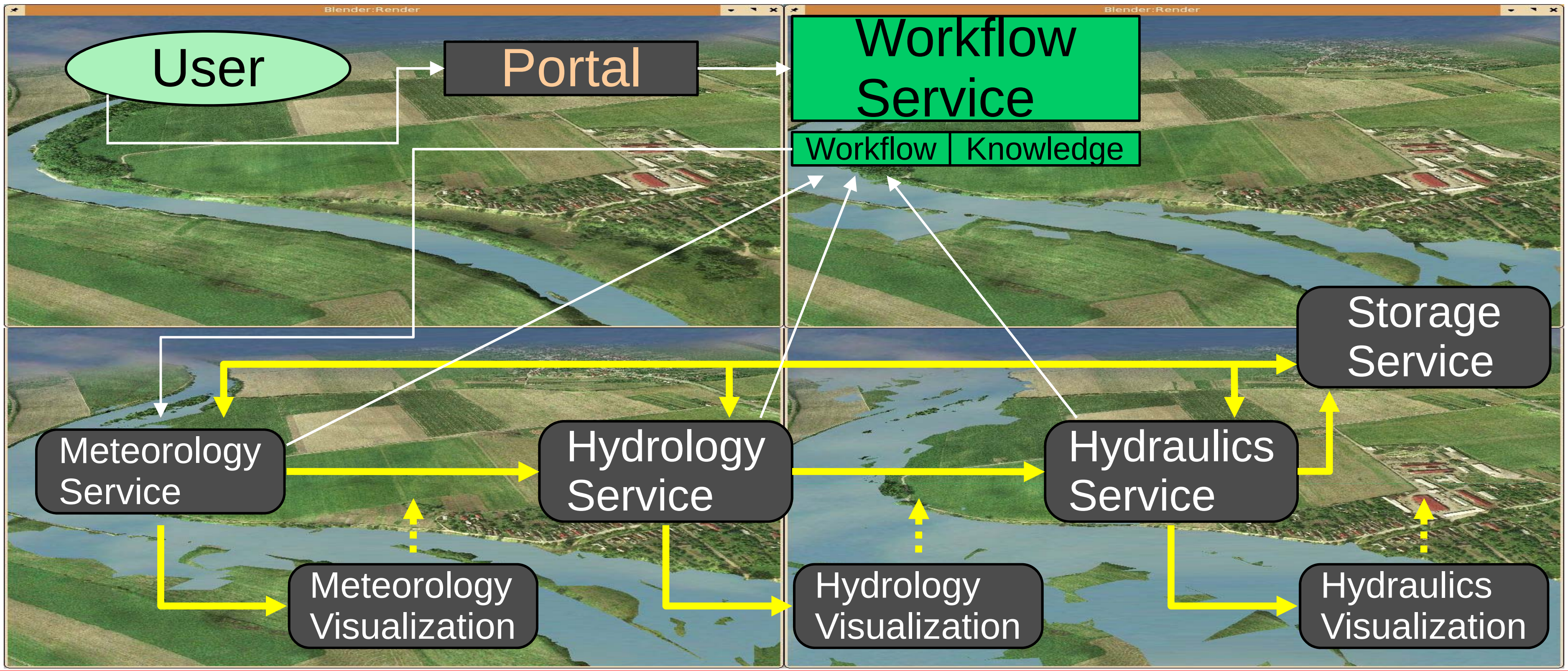
Outline

- Scientific workflows
- Workflow specification
  - End-user programming
  - Automatic composition
- Workflow interoperability
- Workflow provenance
- Workflow scheduling
- Workflow fault tolerance
- From scientific to industrial applications
- Summary

Simulation of Danube Flooding



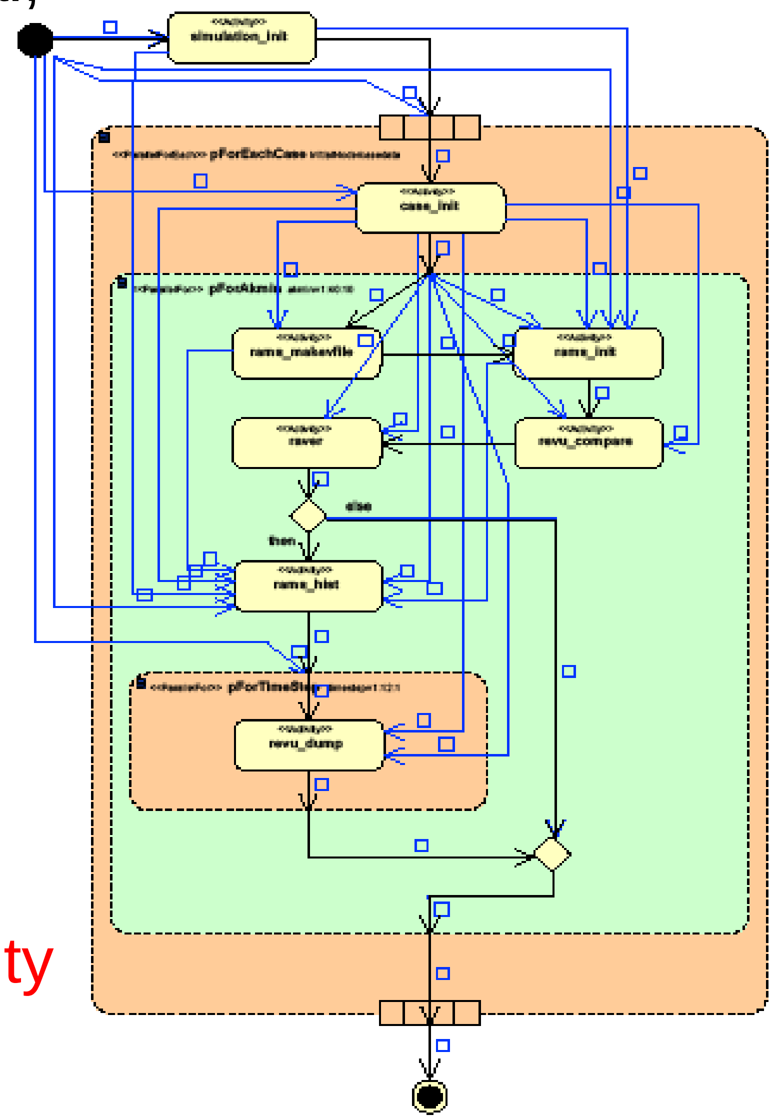
- Workflows are complex applications dynamically constructed from existing services
- Different organisations cooperate to predict the flooding behaviour of the Danube by using Grid sensors, computing and data storage resources, as well as modelling and simulation services



State-of-the-Art in Scientific Grid Workflows

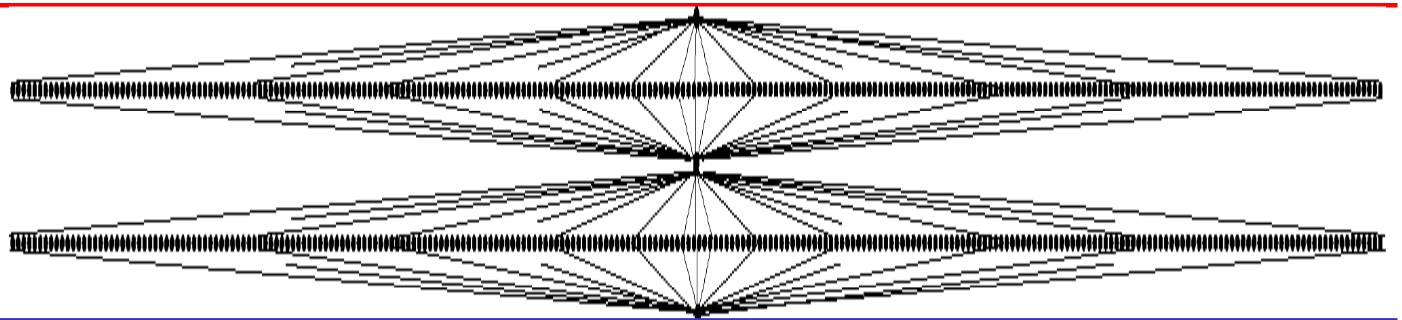
- **<u>Grid workflow</u>** = collection of computational, communication, and interaction tasks that are processed in a well-defined order to achieve a specific goal
- Mostly static workflows
- Fixed control flow dependencies
  - DAGs, if, switch, while and for loops
- Fixed data flow dependencies
- Mechanisms for expressing parallelism
  - Independent tasks, parallel for loops
- Two levels of workflow specification
  - XML-based programming
  - Graphical modeling
- No widely accepted workflow modeling and programming standard in the Grid community

- MeteoAG workflow



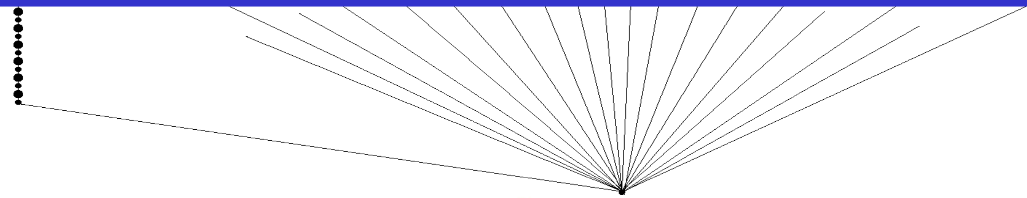
“Small” Scientific Workflows

- WIEN2k
  - Material Science

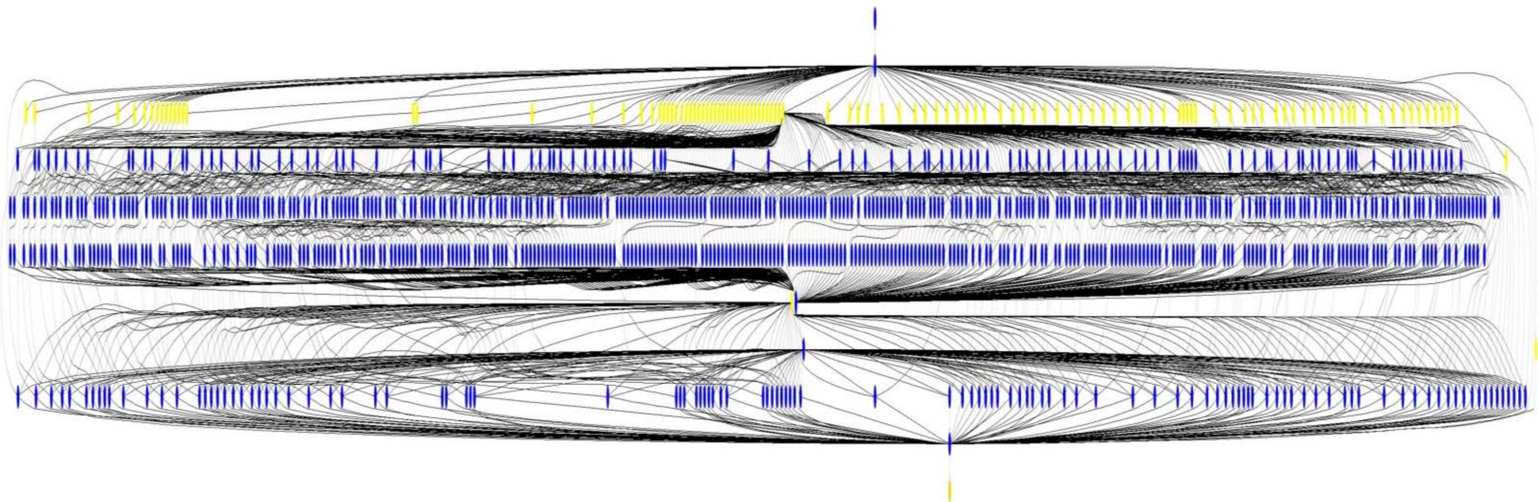


Existing Scientific Workflows with thousands of tasks remind a lot of compiler-internal Abstract Syntax Tree representations

  - Hydrology



- Montage
  - Astronomy

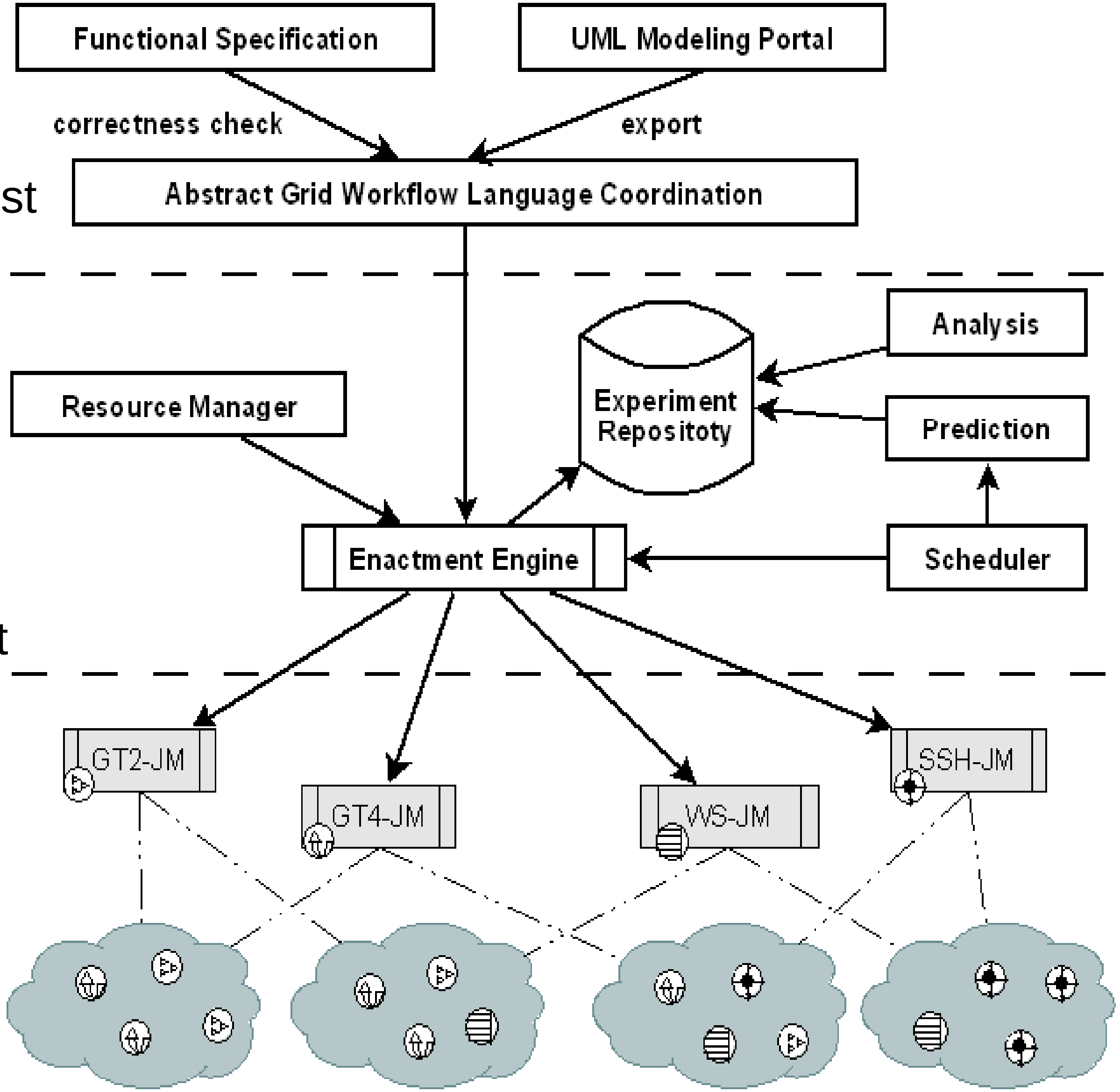


User-level Workflow Composition

- Paper in CCGrid conference, 2007
- Workflows follow an imperative programming model
- Java, C, Fortran, assembly are imperative programming languages
  - Programs are a workflow of instructions
  - Skilful reuse of data stores is the key for **performance**
    - Registers, caches, main memory, hard disks, storage systems
  - Assignments are destructive ⇒ **programming errors**
    - A data store containing a wrong value = bug
- Grid workflow languages
  - Instruction = component, service, task, activity
  - Data ports = variables (data stores)
  - Data flow dependencies = assignment statements
  - Control flow dependencies: sequence, while, for, if, switch, goto
- Grid workflow languages are Turing complete
  - Same complexity and prone to the same programming errors as assembly languages

Two Stage Programming

- Formal functional specification (“what”)
  - Written by the application scientist
  - Based on expression (function) evaluation model
  - No explicit memory allocation
  - No explicit variable assignment
- Imperative workflow coordination (“how”)
  - Written by the computer scientist (manually or through a compiler)
  - Grid distribution and parallelism
- Correctness checker
  - Ensures correct coordination
  - Augment data store with semantics (value names)



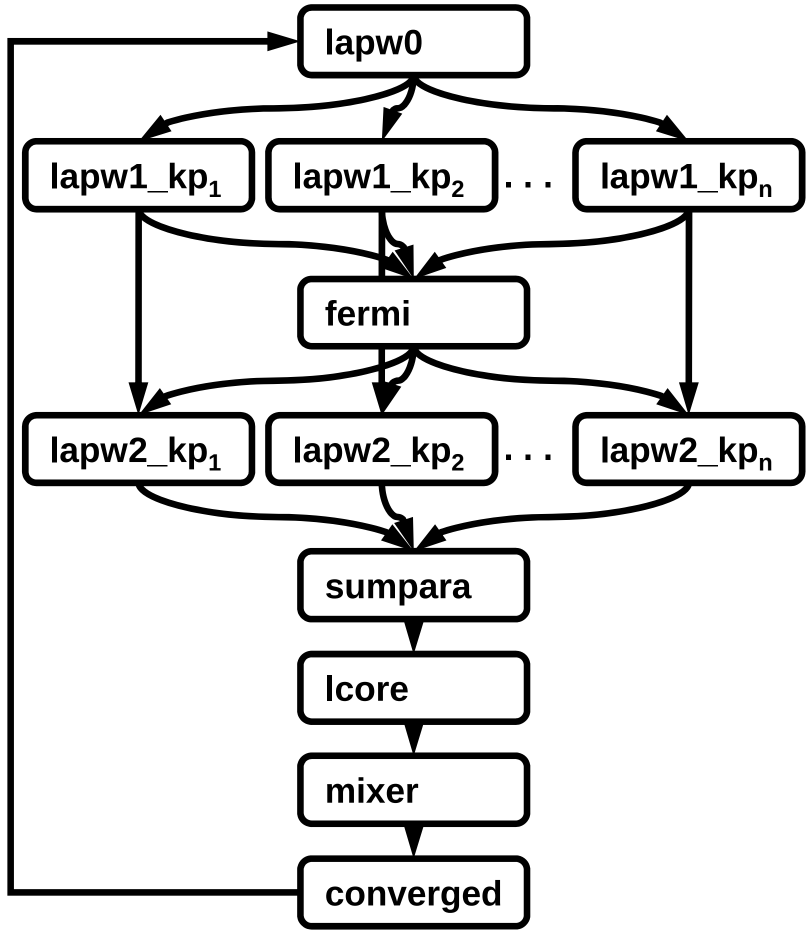
Case Study: WIEN2k Specification

- Recursive definition rather than sequential loop

```
fun wien2k : string * int -> string
    wien2k(in_pack, i) =
        if i = 0 then wien2k_iter(in_pack)
        else
    wien2k_iter(wien2k(in_pack, i-1))

output wien2k(in_pack(), n())
precondition n() >= 0
postcondition
    converged(wien2k(in_pack(), n()))
```

- Material science workflow application

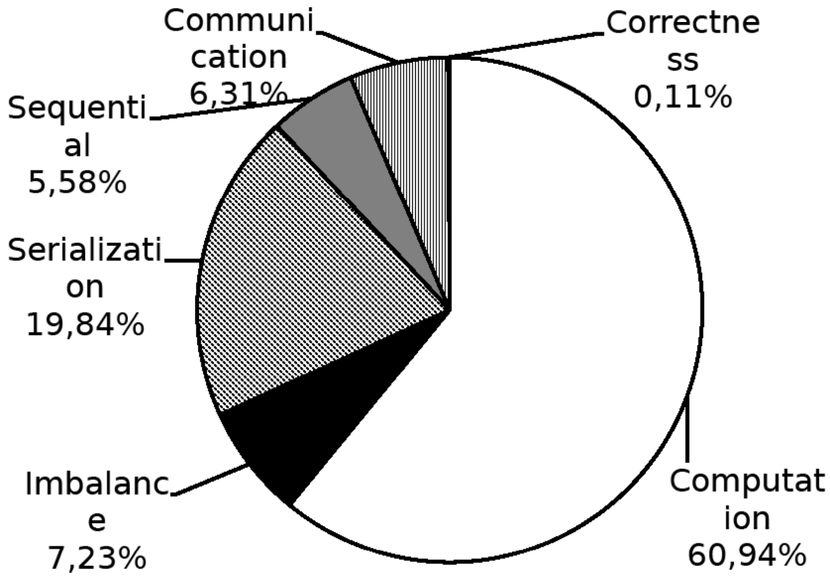


WIEN2k Case Study:
Correct and Efficient Coordination

coordination wien2k
input in_pack : () -> string
A = wien2k(in_pack, 0)
i = 0
while not converged(A) do
assert i >= 0
B = wien2k(in_pack, i) <- A
A = wien2k(in_pack, i+1) | wien2k <- B
i = i + 1
assert converged(wien2k(in_pack, i) <- A)
output wien2k(in_pack, i) <- A

- Annotate data ports with semantic information from the specification to ensure its correctness (value names)

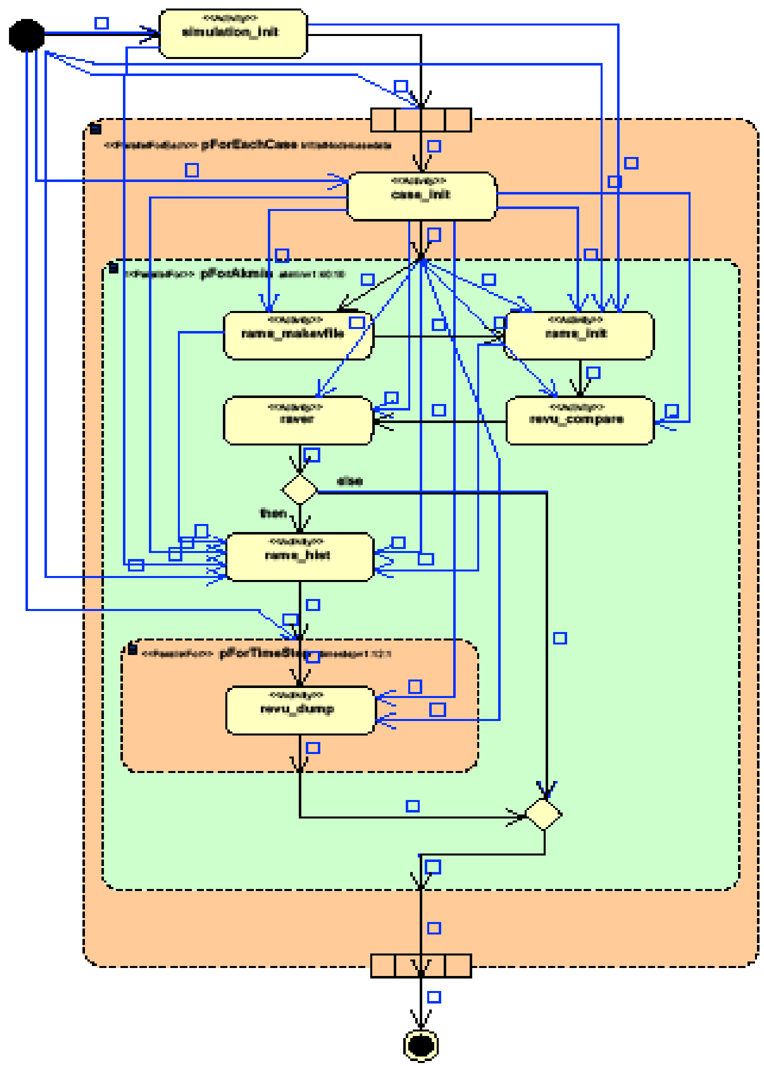
- Full activities
- Fetch activities
- Step activities



Automatic Workflow Composition

- Automatic creation of (partial) workflows at
  - Resource level (runtime)
  - Developer level (offline)
- Build a domain-specific ontology comprising semantic descriptions of activity types
- Start from semantic description of the input and output data
- Use the ontology to automatically compose activities in a workflow that produces this I/O mapping
  - Automatically resolve data dependencies using the ontology information
- Drawbacks
  - Shifts the complexity from workflow composition to ontology creation
  - Semantics technology is very slow which is at odds with dynamic workflows
- Build comprehensive domain-specific ontologies as community efforts

- MeteoAG workflow



Grid Workflow Interoperability

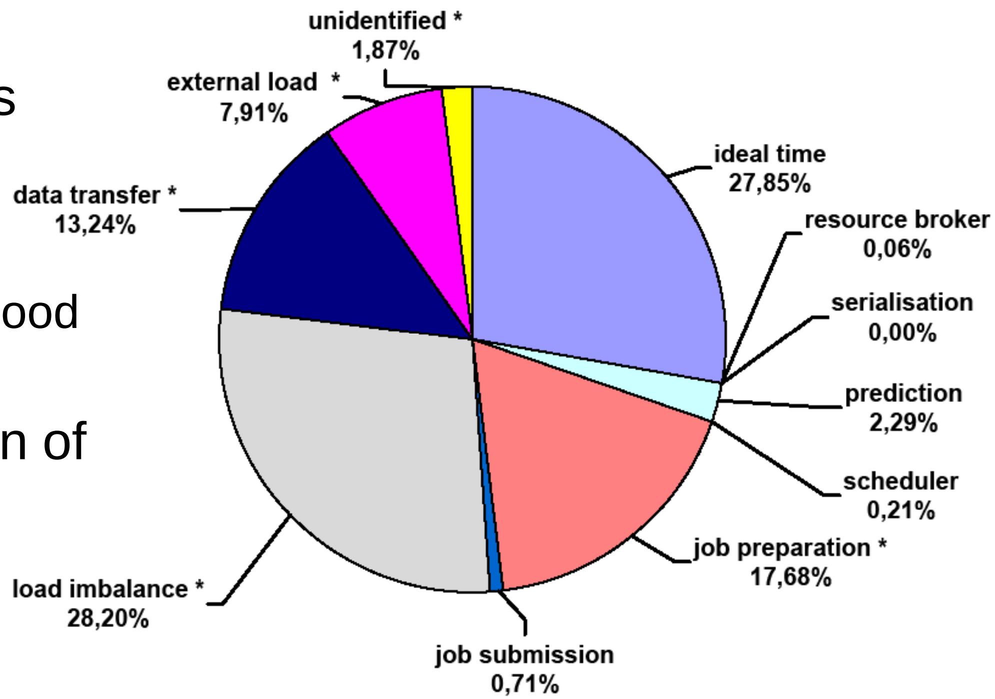
- Most workflow systems disallow execution of a workflow with a different system
- Workflow interoperability is crucial for the survival of most workflow systems
  - Work cannot be justified in application development for a specific system that might be terminated when funding runs out
- Interoperability facets
  - Common high-level workflow language (XML-based)
    - O(1) complexity
  - Intermediate language seen by enactment engine
    - O(n) complexity
  - Transformation bridges among workflow systems
    - $O(n^2)$ complexity
  - Interoperable middleware services
    - Needs standard protocols like Web services

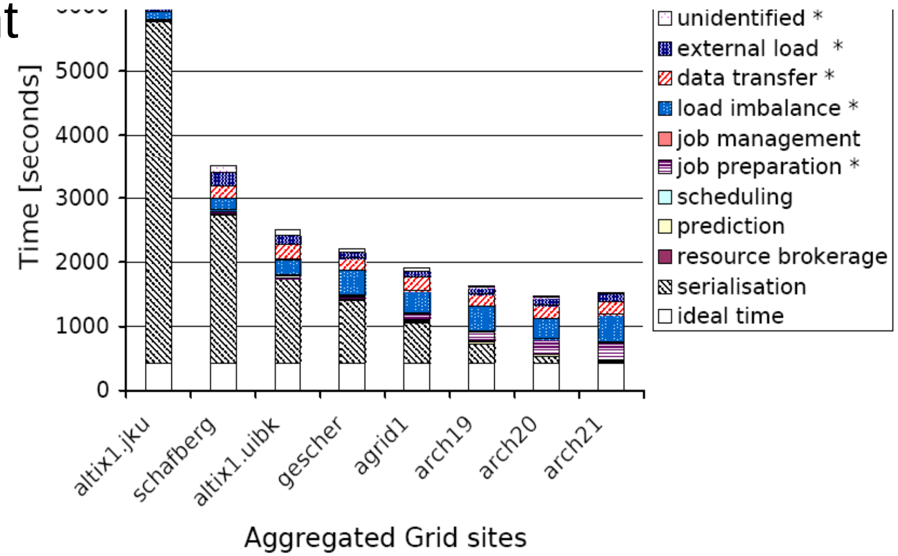
Workflow Provenance

- Provenance = origin or the source of something, or the history of the ownership or location of an object
- For workflows, provenance is any kind of historical data related to the development and execution of a workflow together with its source
- Provenance is principally needed for characterization, reproducibility and verification of results
- Currently provenance information is today highly fragmented
  - emails, Wiki entries, databases, journal references, code comments, compiler options
- Many workflow systems claim support for provenance if they have some monitoring services
- Provenance is much more than monitoring
  - Constraint specification (pre- and post-conditions)
  - Monitoring and recording
  - Provenance store
  - Policy management
  - Audit reports
- Provenance can support many Grid middleware services
  - performance analysis, scheduling, resource management, fault tolerance

Workflow Scheduling

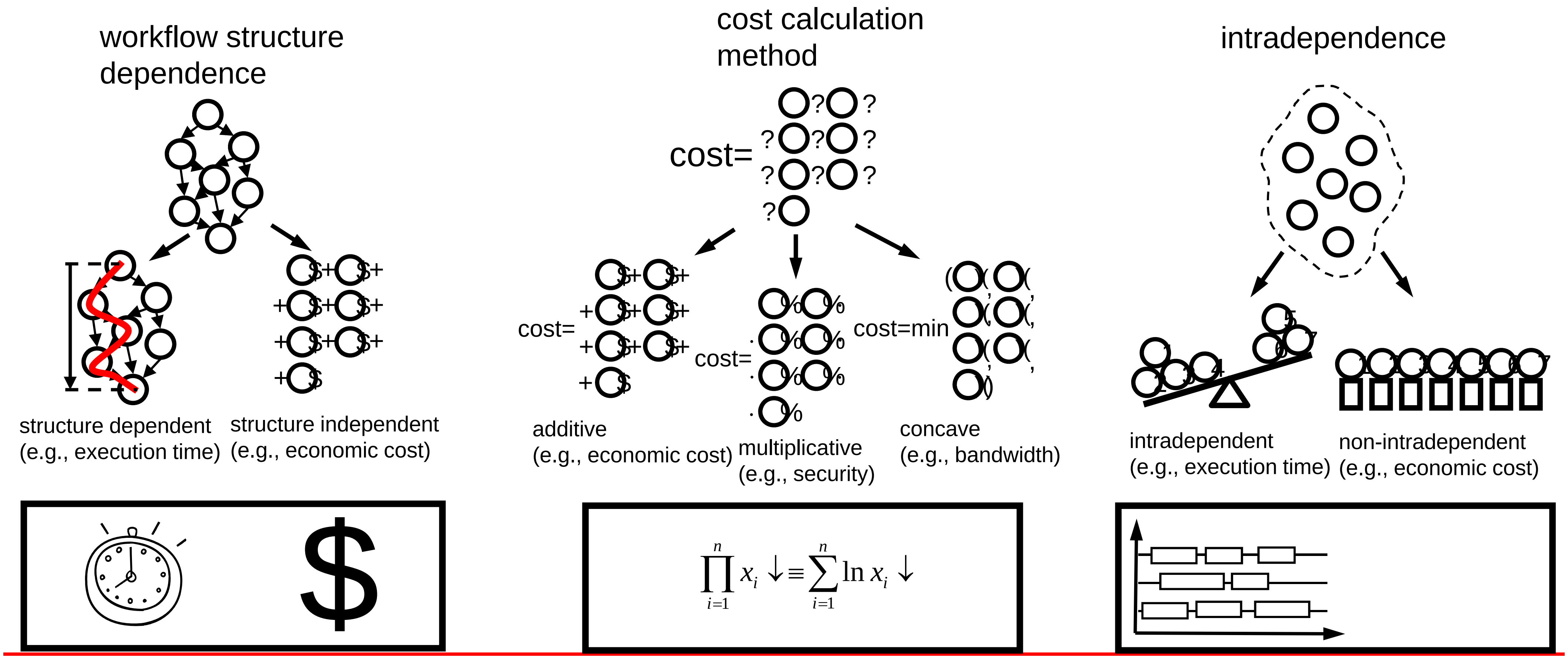
- Map a workflow of *N* tasks onto *M* Grid sites
- Only workflow makespan addressed so far
  - NP-complete optimization problem
  - Many heuristic algorithms that converge to good solutions
- Real overheads not considered in evaluation of the objective functions
- Simulation not based on real workloads
  - Execution completely different from the plan
- **Quality of Service** negotiation and enforcement
  - The challenge is to build QoS enforcement strategies over best effort protocols
  - Best effort TCP/IP protocol
  - Local job queuing systems operate in best effort mode
- SLAs (business) → QoS (resource management) → metrics (fabric)





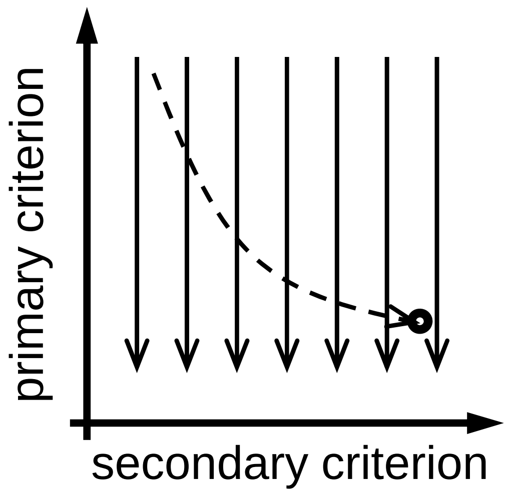
Multi-Criteria Scheduling

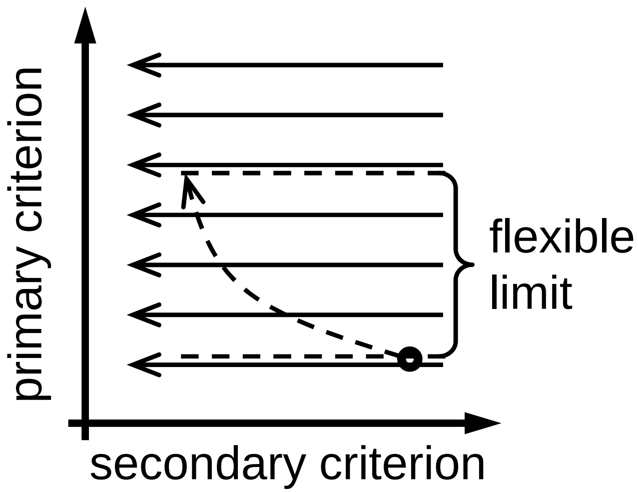
- Optimization of multiple non-functional parameters
  - execution time, cost, reliability, security, availability
- Taxonomy of workflow scheduling



Bi-criteria Scheduling

- Primary criterion plus a flexible constraint for the secondary criterion
- Two-phase optimization based on dynamic programming
- Optimize the schedule for the primary criterion
  - NP-complete for intradependent criteria (execution time using the HEFT algorithm)
  - Trivial for non-intradependent criterion (simple greedy approach) (cost)
  - Result is a preliminary solution
- Modify the preliminary solution, optimizing the secondary criterion
  - The primary criterion kept within the flexible limit
- Problem described as multiple choice knapsack problem





Fault Tolerance Questionnaire

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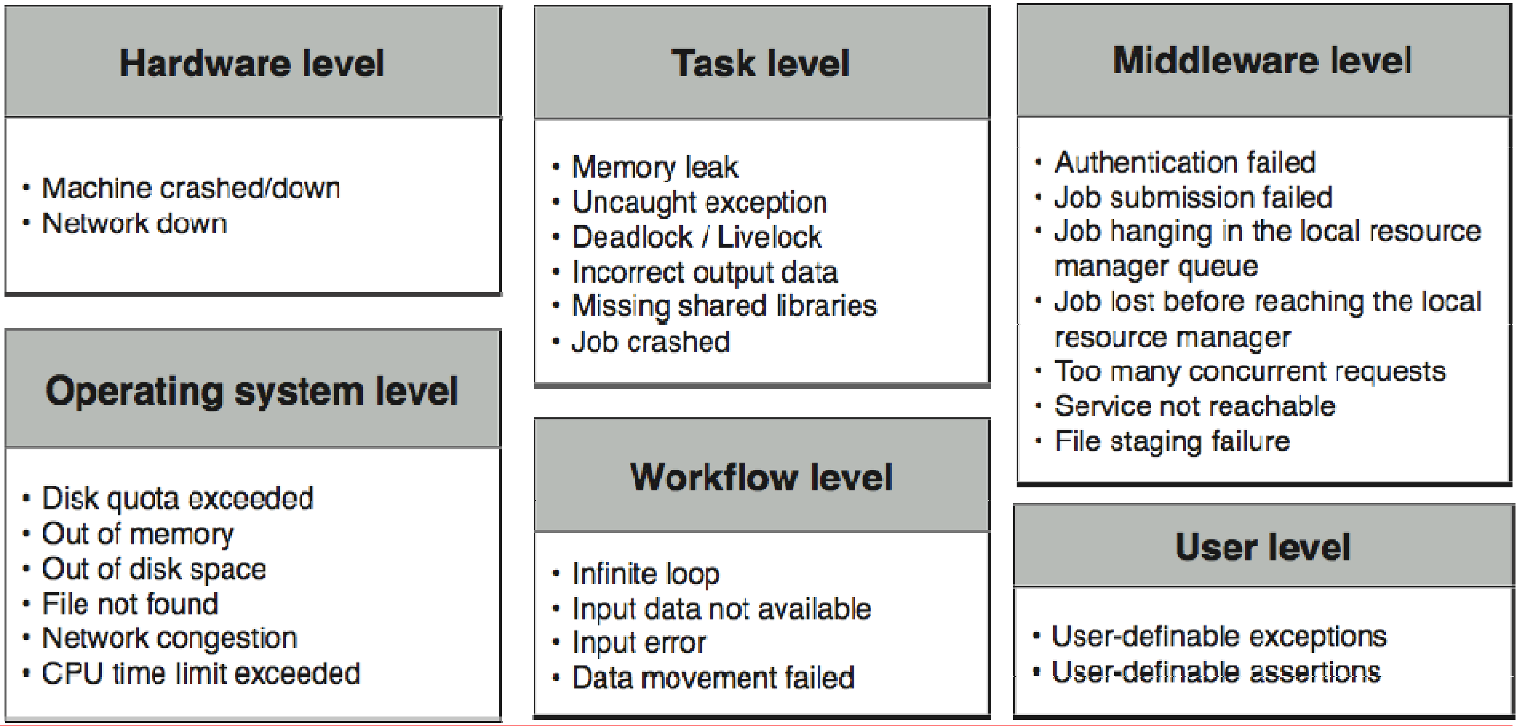
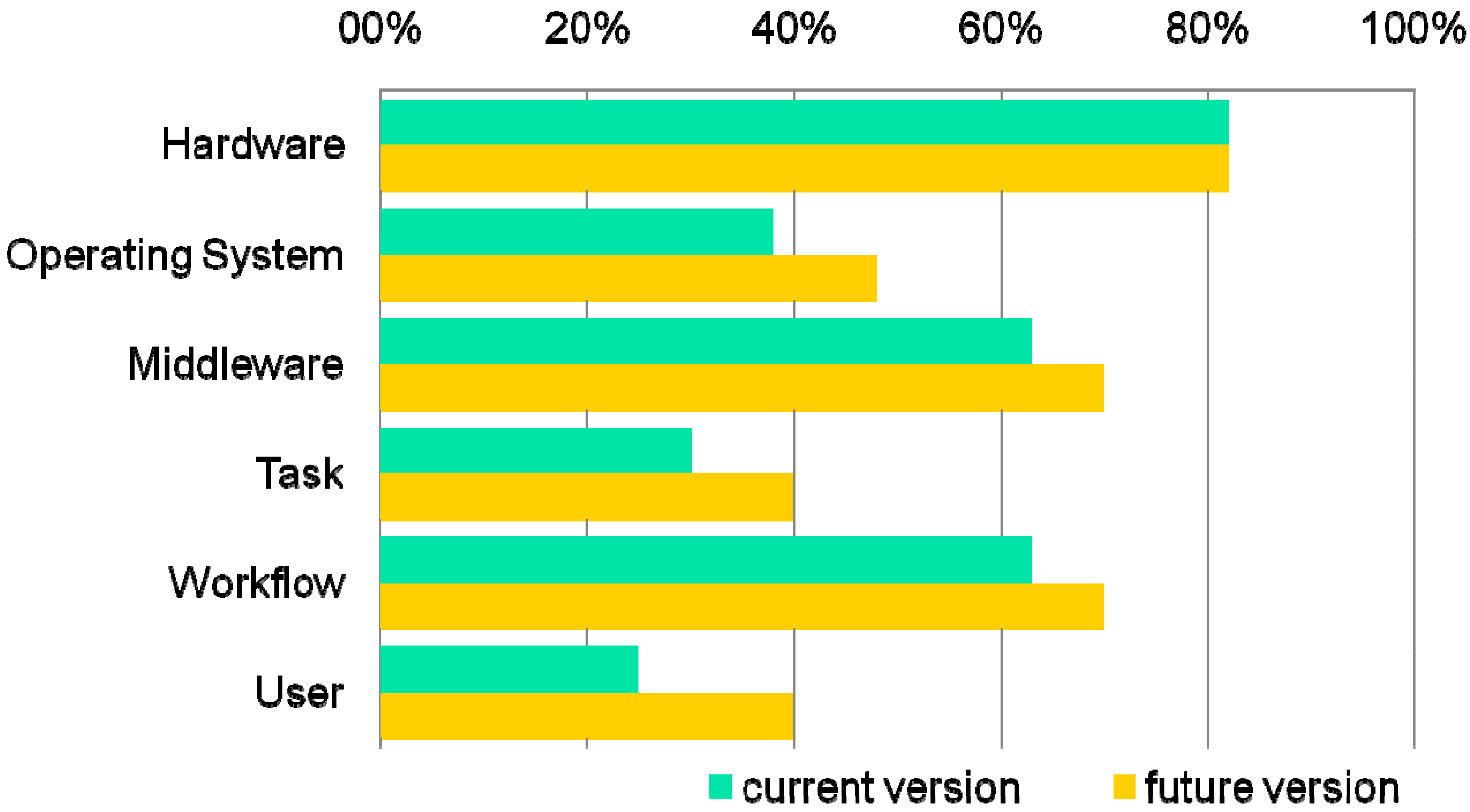
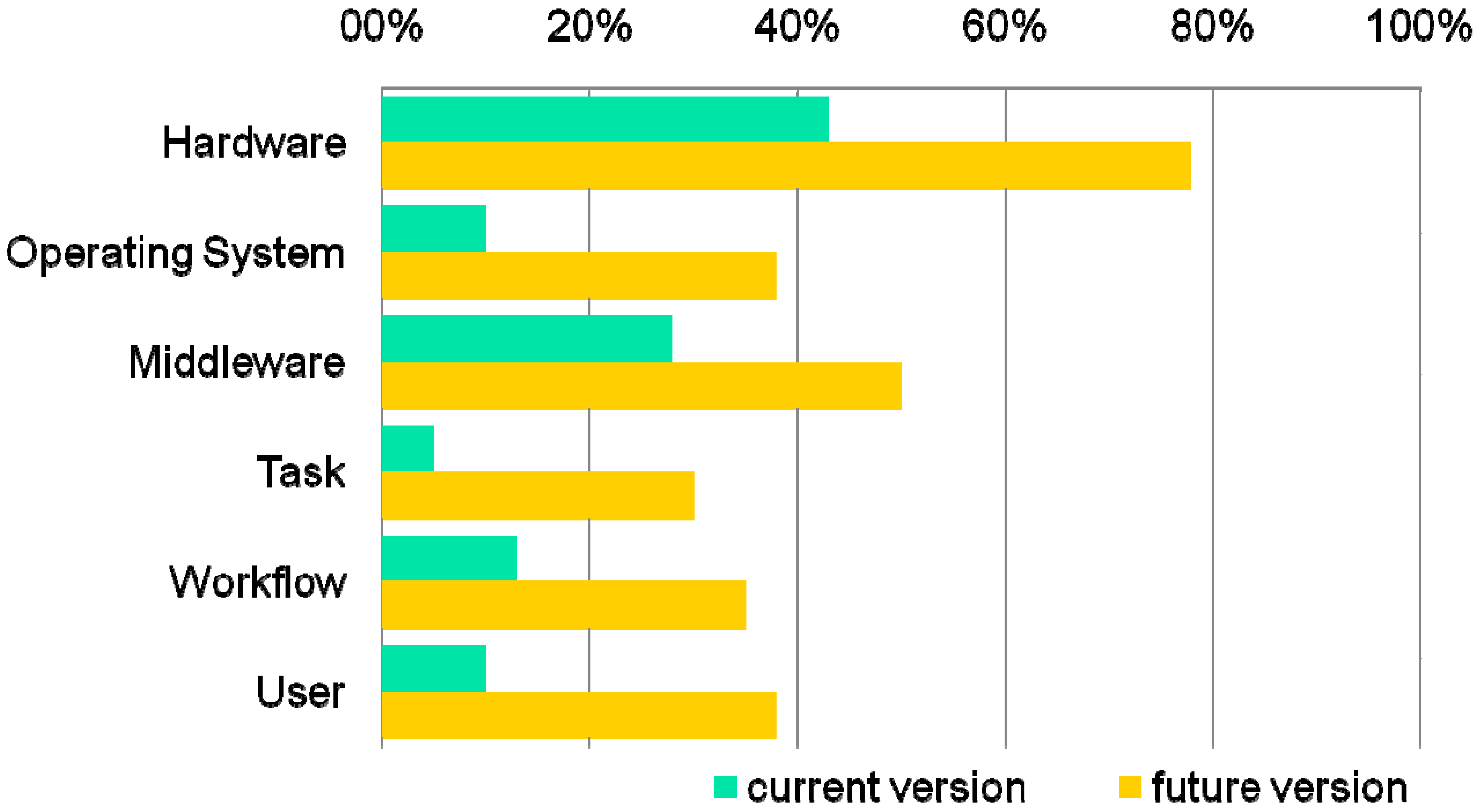
- Questionnaire sent to workflow system developers
  - Fault detection, recovery, and prevention
- ASKALON, Chemomentum, Escogitare, GWEE, GWES, Pegasus, P-GRADE, ProActive, Triana, UNICORE 5



Faults Detected by an Average System



Fault Recovered by an Average System



From Scientific to Industrial Applications
Massively Multiplayer Online Games

ECHOGRID
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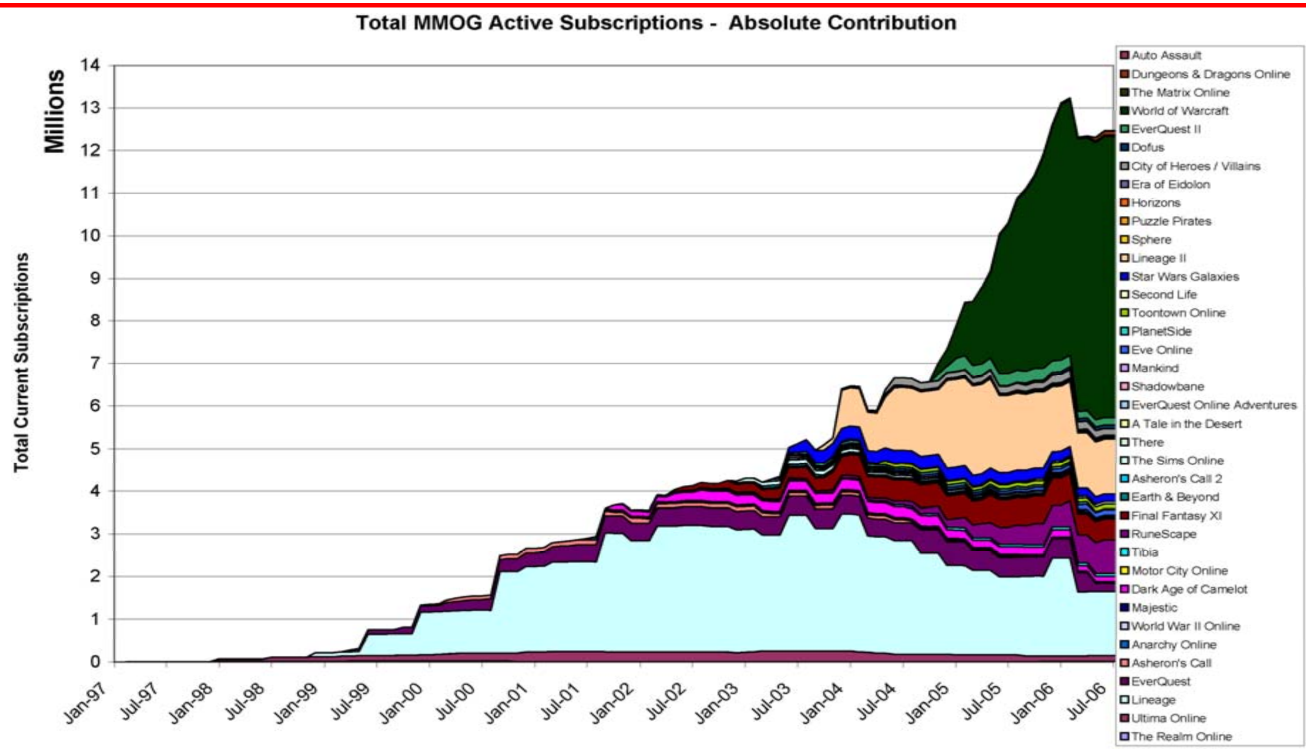
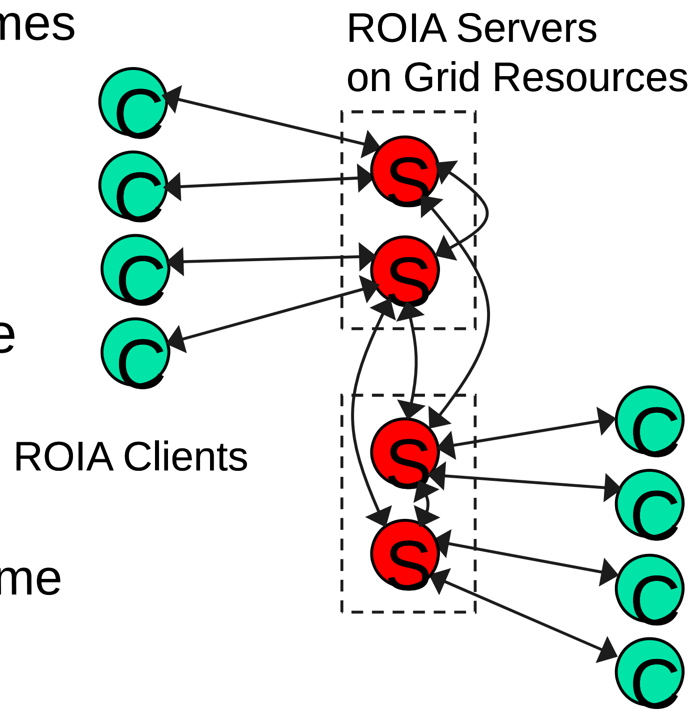
MMOG Popularity



- Over the last 10 years the market size has increased by 20 fold
- 60 million people by 2011
- Entertainment Software Association (ESA)
  - Size: 7 billion USD
  - 300% growth in the last 10 years

MMOG Challenges for the Grid

- Real-Time Online Interactive Applications (ROIA) as a new class of Grid applications
  - Multiple users share the same application instance
  - Impact the dynamics of the application as a community
- Increase the maximum number of players in one session
  - 64 in fast-paced First Person Shooter (FPS) action games
- Virtual Organisations
  - Ad-hoc and dynamic
  - Anonymous users sharing pseudonyms
  - Cheating prevention
- On-demand provisioning of compute servers to game sessions based on user load
  - Avoid over-provisioning
- Real-time QoS requirements
  - State update rate per second from game servers to game players
  - 10 – 60 Hz in fast-paced FPS action games



Summary

- Workflow is a low-level paradigm for application scientists
  - Workflow parallelisation and distribution are runtime optimisations that should be hidden to the application scientists
- Automatic workflow composition
  - Limited by building domain-specific ontologies
- Existing workflow systems comply to no standards and do not interoperate
- Scheduling makespan objective function does include large Grid overheads
- Scheduling validations are not based on real workloads
- QoS support on top of best effort protocols
- Multi-criteria scheduling
- Online games as a new class of socially important applications with huge market potential
- Invisible Grid is still far away
  - Move from programming to abstract modeling
  - Dynamic binding of model to implementation
  - Dynamic software deployment