Advances in e-Science and e-Research: e-Infrastructures for Modelling and Simulation

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Presentation Key Question

- Significant investment in e-Infrastructures has brought about a step change in research in areas such as physics, biology and medicine
- What benefits can e-Infrastructure technological advancements bring to Modelling and Simulation?
Overview

- ICT Innovation Group
- Modelling and Simulation (M&S)
  - COTS Simulation Packages (CSPs)
- e-Infrastructures
- e-Infrastructures for M&S
- Conclusions
ICT Innovation Group, Brunel University

- Technology & knowledge transfer of advanced computing techniques into academia and industry
  - Research, consulting, training and teaching
  - Five academic staff, 3 PDRA + external collaborations
  - 9 PhD Students
  - > £1 million funding
  - Journal of Simulation & ORS Simulation Workshop

- Main areas
  - Modelling and Simulation (Industry & Academia)
  - e-Infrastructure Studies (Europe, Africa)
  - Medical Device Industry Innovation
  - Synthetic and Systems Biology
### Some outputs

#### Distributed Simulation
- EPSRC Network GROUPSIM
- CSPI Forum, CSPI PDG
- IMSS Project (NTU PDCC, Singapore and others)

#### Grid/Cloud Computing
- WINGRID/GridAlliance
- Industrial projects (Ford, ING, Saker Solutions, Simul8 Corp, WSP, etc.)

#### Research Infrastructure
- BELIEF II
- ERINA4Africa
- eI4Africa
- MAP-Guide
- Cumberland Initiative
- UK ORS Simulation Study Group, ACM SIGSIM

#### M&S
- MATCH Tools and Training
- Centre for Synthetic and Systems Biology
- Campus Grid @ Brunel

#### Other
- Centre for Synthetic and Systems Biology
- Campus Grid @ Brunel
Overview

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Modelling & Simulation

- Commerical-off-the-shelf Simulation Packages (CSPs)
  - Arena, AnyLogic, Flexsim, Simio, Simul8, Witness, etc.
  - Widely used to investigate process-based systems in commerce, health, manufacturing, logistics, transportation
  - Discrete-event simulation (some ABS and/or SD)
  - Visual Interactive Modelling (drag and drop)
  - Animated (2D/3D)
  - Methodological support
  - Users tend to be Operational Researchers/Management Scientists
Screenshot of Simul8 (http://www.simul8.com/)
Example of Simul8 MAP-Guide Project: Prostate Cancer Clinical Pathway v7 in Simul8
Screenshots from Flexsim courtesy of Saker Solutions (http://www.sakersolutions.com/)
Overview

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An e-Infrastructure is

- an environment where resources—hardware, software, and content—are readily accessible and can be easily shared.
- It integrates networks, grids, middleware, computational resources, experimental workbenches, data repositories, tools and instruments, and operational support for virtual organizations.

Supporting worldwide advances in physics (e.g. physics (LHC Grid), biology (biomed) and medicine (Healthgrid))

# e-Infrastructures

<table>
<thead>
<tr>
<th>Global Virtual Research Communities</th>
<th>e-Infrastructure-based Applications</th>
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<tbody>
<tr>
<td><strong>Common middleware support for scientific facilities</strong></td>
<td>e.g. Scientific Digital Repository Access, Remote instrumentation, Collaboration Support</td>
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<tr>
<td><strong>Distributed &amp; High Performance Computing</strong> (EGI, TeraGrid, PRACE, etc.)</td>
<td><strong>High Performance Network Infrastructure</strong> (GEANT, TEIN, ALICE, etc.)</td>
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### Sub-Saharan Undersea Cables

<table>
<thead>
<tr>
<th>Cable</th>
<th>Capacity</th>
<th>Status</th>
<th>Year</th>
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<tbody>
<tr>
<td>SEAS</td>
<td>320 gigabits</td>
<td>Active</td>
<td>Q3 2012</td>
</tr>
<tr>
<td>SAT3/SAFE</td>
<td>340 gigabits</td>
<td>Active</td>
<td></td>
</tr>
<tr>
<td>TEAMs</td>
<td>1280 gigabits</td>
<td>Active</td>
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<tr>
<td>Seacom</td>
<td>1280 gigabits</td>
<td>Active</td>
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</tr>
<tr>
<td>Lion2</td>
<td>1280 gigabits</td>
<td>Active</td>
<td>Q2 2012</td>
</tr>
<tr>
<td>Lion</td>
<td>1300 gigabits</td>
<td>Active</td>
<td></td>
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<tr>
<td>MailN OnE</td>
<td>1920 gigabits</td>
<td>Active</td>
<td></td>
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<tr>
<td>GLO-1</td>
<td>2500 gigabits</td>
<td>Active</td>
<td></td>
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<tr>
<td>EASSy</td>
<td>3840 gigabits</td>
<td>Active</td>
<td></td>
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<tr>
<td>WACS</td>
<td>5120 gigabits</td>
<td>Active</td>
<td>Q2 2011</td>
</tr>
<tr>
<td>ACE</td>
<td>5120 gigabits</td>
<td>Active</td>
<td>Q3 2012</td>
</tr>
</tbody>
</table>

### African Undersea Cables (2012)

- [http://manypossibilities.net/african-undersea-cables](http://manypossibilities.net/african-undersea-cables)

Version 26 - Mar 2011

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**Mediterranean Undersea Cables**

- **Atlas Offshore**: 320 gigabits, Active
- **SEA-ME-WE 4**: 1280 gigabits, Active
- **I-ME-WE**: 3840 gigabits, Active
- **EIG**: 3840 gigabits, Active

N.B. Several smaller Mediterranean cables not shown.
Key Issues (UK)

- Network
  - The supra-exponential growth in data and the need to share this data for effective collaboration. Securing and expanding this is a priority.

- Software People and Skills
  - Robust and usable software at every level of the e-Infrastructure supported by skilled software engineers and developers.

- Compute
  - On-going national need for robust computing infrastructure to facilitate the ongoing need for to run simulations. Cloud (e.g. Amazon EC2) emerging.

- Data
  - Expanding data deluge. (Need for curation, management and certification).

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  - COTS Simulation Packages (CSPs)
- e-Infrastructures
- e-Infrastructures for M&S
- Conclusions
e-Infrastructure Involvement/Influence

- Bringing Europe’s eLectronic Infrastructures to Expanding Frontiers (BELIEF 1 & 2) (Europe, Latin America & India)
- Organisation of e-Infrastructure Concertation events (Europe)
- Exploiting Research Infrastructures potential for Boosting Research and Innovation in Africa (ERINA4Africa) (Europe & Africa)
- el4Africa (Europe & Africa)
- European Desktop Grid Initiative Subcontract
e-Infrastructures for M&S

- An *e-Infrastructure for M&S* (in the context of this talk) is
  - an environment where resources — *COTS simulation packages and ancillary software* (e.g. Excel), models, data, etc. — are readily accessible and can be easily shared *and/or interoperated*
  - It integrates networks, grids, middleware, computational resources, data repositories, and software tools within (virtual) organizational boundaries

- What could be the specific benefits?
e-Infrastructures for M&S – Benefits?

- **Collaborative Support**
  - Save project time and costs by remote collaboration

- **High Speed Experimentation**
  - Reduce experimentation time and/or increase depth of analysis

- **Simulation Interoperability/Distributed Simulation**
  - Reduce experimentation time and/or increased analysis, facilitate distributed model development, overcome large distributed model problems

- **Data (Artefact) Management**
  - Project cost reduction by better management of all simulation project artefacts, integration with other projects, cheaper model development through reuse
e-Infrastructures for M&S
Collaborative Support

- Groupware
- Plenty of off-the-shelf software (Messenger, Skype, GotoMeeting, etc.)
- Application sharing
- On-line training opportunities
- Cannot replace face-to-face meetings but can certainly reduce model development time (less time travelling!)

BUT!
- Some practitioners unaware that groupware exists!
e-Infrastructures for M&S
High Speed Experimentation

- COTS Simulation Packages
  - Nearly all run under Windows
  - Must be installed
  - Access to local installed data sources (databases, spreadsheets, etc.)
  - Are licensed (typically by copy)
  - Do not have direct Grid/Cloud Computing support
  - Model runtimes seconds to hours
**e-Infrastructures for M&S**

**High Speed Experimentation**

- **Grid and/or Cloud Computing**
  - Must be easy to implement and support
  - M&S is costly! Must be a clear business case for Grid investment
  - Users will have OR/MS skill set - must be deployed in their ‘world’ (experimentation managers)
  - Institutional IT management plays a key role and must be on board
Desktop Grid Computing and M&S

- Ford
  - WINGRID/WITNESS
- ING
  - WINGRID/EXCEL
- GRIDALLIANCE
  - WINGRID/SIMUL8
- Systems Biology
  - CONDOR/SIMAP
  - SZDG/SIMAP
- Saker Solutions
  - SAKERGRID/FLEXSIM
- SIMUL8
  - SZDG/SIMUL8 & EXCEL

2008+ Literature

2008

2009

2010

2011
Kite, et al. (2011) WSC 2011

2012
Taylor, et al. (2023) SW’12
Systems Biology

SIMAP Systems Biology Simulation Tool (Glasgow/Brunel)
Uses SBMLODEsolver (SOSLib) to compute the concentrations of species over time.

Biochemical Systems
- e.g. protein kinase signalling pathways

Translating the biological system (e.g. a reverse reaction)

\[
\frac{d[A]}{dt} = -k_1[A] + k_2[B] \\
\frac{d[B]}{dt} = k_1[A] - k_2[B]
\]

For subsequent analysis

Orton, et al. (2005) Biochem J
Models are specified by Systems Biology Mark up Language (SBML)

- `<species id="mw132274B8_625A_4C28_8B55_2B0D5480F46A" name="c558" compartment="mwE8BC1"
   initialAmount="0">
   <notes>(EGF:ErbB1:ATP::EGF:ErbB1_h:Inh)-HalfActive</notes>
   <annotation>plasma membrane</annotation>
</species>
</listOfSpecies>
- `<listOfParameters>
   <parameter id="mw8b4a0e01_6b31_4b99_93ac_0a1df7ad377b" name="kd1" value="0.0033" />
   <parameter id="mw10be3c14_8b28_4a67_b3e6_5b2987d003d0" name="k1c" value="800" />
   <parameter id="mw817a95bd_e5c8_4a5c_b088_01810daffd40c" name="kd1c" value="1" />
   <parameter id="mw611b22c9_7afd_4364_98d7_fb6ed1ce06b8" name="kd1d" value="0.1" />
   </listOfParameters>`
MAPK model (732 species, ~ 244 parameters)
Grid Computing & Systems Biology

- Two kinds of analysis that can benefit from grid computing
  - Parameter scanning and Parameter estimation
- Parameter scanning changes kinetic rates and creating new models the number of models can grow very fast
- ‘Typical’ model runs at around 20-30s (Contemporary PC)
  - 2 parameters over 10 values @ = ~11 hours
  - 3 parameters over 10 values @ = ~3 months
Desktop Grid Architecture

- Previous studies on CONDOR

- Recent studies on SZTAKI Desktop Grid (SZDG)
  - Based on volunteer computing adaptation based on Berkley Open Infrastructure for Network Computing (BOINC)
  - EDGeS & EDGI projects
    - www.edges-project.eu, www.edgi-project.eu
  - Any application can run, does not use credits
  - Westminster Local Desktop Grid (WLDG)
    - An implementation of SZDG
    - 1500 PCs, four different sites
BOINC

- 1 Gigaflop machine running for a day ~ 200 credits
- => BOINC combined ~ 4.5 Million Gigaflops/day
SZTAKI Desktop Grid (SZDG)

WS-PGRADE
(User Interface/Portal)

gUse
(Workflow Processor & Services)

3G Bridge

BOINC Client
GenWrapper
Legacy Application

BOINC Client
GenWrapper
Legacy Application

BOINC Client
GenWrapper
Legacy Application

Workflow Description

BOINC Server Components
 Scheduler
 Data Server
 BOINC Task DB

SZDG Server

gUse DG Submitter

Tasks

Work Units

Workflow
University of Westminster Local DG
Over 1500 Windows PCs from 6 different campuses

Lifecycle of a DG node:
1. PCs basically used by students/staff
2. If unused, switch to Desktop Grid mode
3. No more work from DG server -> shutdown (green solution)

1. New Cavendish St 576 nodes
2. Marylebone 559 nodes
3. Regent Street 395 nodes
4. Wells Street 31 nodes
5. Little Titchfield St 66 nodes
6. Harrow Campus 254 nodes

Courtesy of Centre for Parallel Computing, University of Westminster
<table>
<thead>
<tr>
<th>Workflow name:</th>
<th>bioness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Note:</td>
<td>2011-5-26</td>
</tr>
<tr>
<td>Workflow Graph:</td>
<td>BioNessie01 --</td>
</tr>
<tr>
<td>Workflow Template:</td>
<td>![Workflow Diagram]</td>
</tr>
</tbody>
</table>

Options for saving:
- Delete old instances
- Do not delete old instances
WS-PGRADE Portal Workflow

Initialise

Generator

SIMAP

Collector

SBML models

Simulations/Job

Storage address

Results
Job (work unit) Description

- **Inputs**
  - SBML model
  - Script file
  - SBML Odesolver
  - Size: ~2 MB.

- **Output**
  - Zip file contains results for all jobs
  - Size: ~1.5 MB.
Speedup vs Job Completion

100 jobs, 100 simulations per job
30 min to complete ~50% of jobs, 2h 30 min to complete other ~50%
Unknown number of PCs

![Graph: Finished job vs Speedup]

- S: 28 -> 16
Speedup vs Job Completion

point speed up

- 1 sim/job
- 2 sim/job
- 4 sim/job

S: 69 → 42

00:15 00:30 00:45 00:51 01:00 01:26 01:30

Time
CONDOR Speedup (8 sims/job)
Volunteer Computing

Tail Problem

Jobs/Work Units in Progress

Time
Cloudbursting

- Augment the DG infrastructure with virtual cloud resources
- Design a cloud resource scheduler that tackles the tail problem
Cloudbursting: Indicative Results

50 Autodock Jobs Tail Def: 40%, Timeout 25min

Jobs Complete vs Time (HH:MM:SS)

- DG Only
- Cloudbursting

With thanks to Centre for Parallel Computing, 2011
Summary (DG/Systems Biology)

- Some success but limited variable speedup
- More experimentation
  - Cloudbursting
- Possible standardised approach
  - Several SZDG implementations/applications can run on any SZDG platform
  - Links to EGI systems via 3G Bridge
- Portal/job submission technology
  - Developing G-Use Portal for SIMAP
SAKERGRID

- Saker Solutions identified a need to radically reduce the time taken to produce results from a simulation project.
- Joint research Project with Brunel University during 2007-9
- Culminated in the development of SAKERGRID
- 1st Large Scale Client Implementation at Sellafield Ltd (BNFL) 2010

Development Issues

- Testing existing approaches against possible client sites led to development of bespoke Grid implementation
  - Potential wide range of implementation challenges
  - Develop well-understood, in-house technology
- CSP
  - Initially Flexsim
- Integration with Saker’s Scenario Manager
  - Manager/’Portal’
- Assumes
  - CSP/Models/data available locally at worker
  - Client has multiple licences
SAKERGRID Architecture

Client
- Grid Client Application
  - Supplies Data
  - Returns Results
- Grid Middleware

Manager
- Work Queue
- Data Storage
- Grid Middleware

Worker
- Unmodified CSP
  - Supplies Data
  - Returns Results
- Grid Middleware

Corporate Network
Worker registers available CSPs with Manager
Conventional Speedup

![Graph showing speedup with number of machines](graph.png)

- 1 Rep. Scenario
- 5 Rep. Scenario
- 10 Rep. Scenario
- 20 Rep. Scenario
- 40 Rep. Scenario

**Scenario Time (Hours:Minutes)**

**Number of Machines**

Brunel University

sakergrid
Sellafield Ltd UK & Flexsim

- Sellafield Ltd is responsible for safely delivering decommissioning, reprocessing, nuclear waste management and fuel manufacturing activities
- Sellafield Ltd have a network with 22 Flexsim Licences based over 3 sites
- There are up to a dozen client machines that need to submit jobs to the manager
- Workers each hold a Flexsim Licence.
  - They may sit on the same machine as the client.
  - They may sit on a series of dedicated multicore servers running VMware to host multiple Virtual Machine instances.
- Models have runtimes of between 10 mins and 12 hours per replication
- Models are all Flexsim models but using different versions of the software and different libraries
Sellafield Ltd & SAKERGRID

- **User conflict**
  - Running Grid in the background is not always desirable. Some models have a requirement for 2GB of Memory

- **Network infrastructure**
  - Restricted Shared folders on machines

- **Inter-Site networking**
  - Frequent disconnects, sometimes as frequent as every 30 mins.

- **Security**
  - Cannot leave a model and results together on a machine – delete when finished

- SAKERGRID successfully modified to account for these issues
Summary (SAKERGRID)

- DG successfully built with simulation consultant and deployed at client site
GenWrapper
GenWrapper (simul8)
Results

- **Simul8 version**
  - Emergency Room simulation (thanks Dr Vince Knight (Cardiff)!)  
  - Each run 50 seconds  
  - 3 runs per job

- **Simul8 & Excel version (English!)**  
  - National Blood Service model  
  - Each run 25 seconds  
  - 4 runs per job

- In both cases speedup over 8 machines was around 5

- On-going analysis
e-Infrastructures for M&S
High Speed Experimentation

- COTS Simulation Packages (and their ancillary software) can be supported
  - Small runtimes supported
  - License issues
  - Partnership with Vendor vital
  - SZDG Grid probably the best deployment architecture in a “standard” environment (simple to deploy and maintain)
  - Still need to integrate with an Experimentation Manager of some kind
e-Infrastructures for M&S
Simulation Interoperability/Distributed Simulation

Interoperability between (two +) CSPs during a simulation run
e-Infrastructures for M&S
Simulation Interoperability/Distributed Simulation

- **Motivations**
  - Privacy
  - Data transfer/access problems
  - Model composability/update problems
  - Execution Time

- **Illustrative case**
  - Distributed simulation of blood supply chain
  - Korina Katsaliaki (UoT), Navonil Mustafee (Brunel), Sally Brailsford (Southampton), Mark Elder (Simul8)

**Surveys**
Ryde and Taylor (2007) *WSC 2007*
Strassburger, et al. (2009) *WSC 2009*
Boer, et al. (2010) *Journal of Simulation*

Taylor, et al. (2013) *ACM TOMACS*
Simplified National Blood Service Model
Supply Chain of Blood

NBS PTI

Hospital 1

Hospital 2

Hospital 3
Distributed Model

Manager Federate

Run Time Infrastructure

H1

H2

H3
The CSP Controller Middleware utilizes the COM interface to access the Simul8 simulation engine.

COM interfaces used:

- `MySimul8 As SIMUL8.S8Simulation`
- `MySimul8.Open`
- `MySimul8.RunSim`
- `MySimul8.SimulationTime`
- `MySimul8.ExecVL`
- `MySimul8.StopSim`
- `MySimul8.Quit`
The HLA interface specification organises the communication between federates and the RTI into six different service groups.

For our Type-I IRM solution with Simul8 and the RTI, we require HLA-defined services defined under the groups:

**Federation Management**: RTI Calls for creation and deletion of federation; joining and resigning of federates from the federation; and creation and realization of synchronization points.

**Declaration Management**: Calls pertaining to publication and subscription of interactions.

**Object Management**: Calls that relate to sending and receiving interactions.

**Time Management**: RTI calls required to enable time constraint and time regulation and also to advance the federate simulation clock.
CSP Controller Middleware Protocol

RTI

nextEventRequest(nextEventTime)

receiveInteraction(...params,time,....)*

timeAdvanceGrant (newTime)

sendInteraction(...params,time,..)*

Simul8 Adapter

OpenSim(modelName, federateName)

GetNextEventTime()

Input (time, entity)*

RunSim(time) or RunSimNoInteration(time)

Output(time, entity)*

TellSimulationEnd(time)

CloseSim()

Simul8 COM calls

RTI Adapter

Simul8 CSP

Simul8 COM calls
A Standards-based Approach

- COTS Simulation Package Interoperability Product Development Group under the Simulation Interoperability Standards Organization (SISO CSPI PDG)
- Roots in UK EPSRC GROUPSIM Project (2000-2004)
- Formal activity began June 2002
  - (HLA-)CSPIF (August 2002)
    - 16 international meetings, 80+ members
  - SISO Virtual Study Group (Jan 2003)
  - Final report submitted to SISO (Sept 2003)
  - Product Nomination submitted (June 2004)
  - PDG status awarded Oct 2004
  - Now transitioning to SISO CSPI PSG (www.sisostds.org)
Figure 1 - SISO Balloted Product Development and Support Process (BPDSP)
SISO CSPI PDG

- **Aim**
  - to develop standardised approaches to COTS Simulation Package Interoperability

- **First major outcome**

### 2008+ Literature

**2008**
Mustafee and Taylor (2008b) *SW '08*

**2009**

**2010**

**2011**
Taylor, et al. (2011) *WSC 2011*

**2013**
Taylor, et al. (2013) *ACM TOMACS*
Interoperability Reference Models

- Current list
  - Type A: Entity Transfer (3 IRMs)
  - Type B: Shared Resource
  - Type C: Shared Event
  - Type D: Shared Data Structure

- Previously appeared as
  - Type I: Asynchronous Entity Passing
  - Type II: Synchronous Entity Passing (Bounded Buffer)
  - Type III: Shared Resources
  - Type IV: Shared Events
  - Type V: Shared Data Structures
  - Type VI: Shared Conveyor

Interoperability Reference Models

- **Definition:**
  - An interoperability problem *type* is meant to capture a general class of interoperability problem, while an *IRM* is meant to capture a specific problem within that class at the model level.

- **The purpose of an IRM is therefore:**
  - to clearly *identify* the model/CSP interoperability *capabilities* of an *existing* distributed simulation
    - e.g. The distributed supply chain simulation is compliant with IRMs Type A.1, A.2 and B.1
  - to clearly *specify* the model/CSP interoperability *requirements* of a *proposed* distributed simulation
    - e.g. The distributed hospital simulation must be compliant with IRMs Type A.1 and C.1
IRM Type A.1 General Entity Transfer

Federate F1

COTS Simulation Package

Model M1

Q1 → A1

Entity e1 leaves A1 at T1 and arrives at A2 at T2

Federate F2

COTS Simulation Package

Model M2

Q2 → A2

T1 =< T2 or T1<T2?
IRMA Type A.2 Bounded Receiving Element

Federate F1
COTS Simulation Package
Model M1

Federate F2
COTS Simulation Package
Model M2

Entity e1 attempts to leave A1 at T1 and arrive at A2 at T2 in a bounded element (e.g. queue)

Must account for blocking behaviour
Entities arrive from different models potentially at the same simulation time.

The priority rules must be specified and be strictly observed.
Blood supply chain…

- Orders/Blood units are only exchanged
- In terms of interoperability…
  - Distributed NBS model has the functionality of
    - IRM A.1, T1>=T2 (Entity Transfer)
  - Currently does not have the functionality of
    - IRM A.3 (Ordered Queues)
  - Does not require the functionality of
    - IRM A.2 (Bounded buffer)
- Specification then produced in IRL and a FOM and agreed by all parties before implementation

Some other examples

e-Infrastructures for M&S
Simulation Interoperability/Distributed Simulation

- Entirely possible but needs
  - Better COTS Simulation Package Integration
  - More standardisation
  - HLA RTI software cost?
e-Infrastructures for M&S
Data (Artefact) Management

- Project cost reduction by better management of all simulation project artefacts
- Integration with other projects
- Cheaper model development through reuse
A “typical” M&S project
However, models are getting larger…
In reality, in a large system...

- E.g. Healthcare
  - One or more emergency room models
  - One or more outpatient models (orthopaedics, urology, etc.)
  - Ambulance models
  - Social care models
  - Pathway models
  - Health economics models/studies

- Overlap in terms of data, model elements, model scope, results and people
Initial attempt

- DEMO ontology (Fishwick and Miller)
  - Discrete event ontology
- DESC
  - Discrete event simulation component ontology
  - Basic search and discovery architecture

e-Infrastructures for M&S
Data (Artefact) Management

- Experience shows that ontology development is very difficult
  - Automatic extraction
- No solution as the problem needs to be properly conceptualised
  - Arguably a methodology is required prior to the technology
  - Namespace conventions
  - Is a centralised organisational “authority” possible given multiple modellers?
Conclusions

e-Infrastructures for M&S

- An *e-Infrastructure for M&S* (in the context of this talk) is
  - an environment where resources — COTS simulation packages and ancillary software (e.g. Excel), models, data etc. — are readily accessible and can be easily shared and/or interoperated
  - It integrates networks, grids, middleware, computational resources, data repositories, and software tools within (virtual) organizational boundaries

- In this domain of simulation
  - Is it worth it? Is it possible? How long?
Conclusions

**e-Infrastructures for M&S**

- **Collaborative Support**
  - Benefit: **High**
  - Possible: **Easy!**
  - Time: **Now**

- **High Speed Experimentation**
  - Benefit: **High**
  - Possible: **Yes**, with some investment
  - Time: **Near term**
Conclusions

e-Infrastructures for M&S

- Simulation Interoperability/Distributed Simulation
  - Benefit: Evidence suggests in some cases high
  - Possible: Yes, with more research/standardisation
  - Time: Medium term
- Data (Artefact) Management
  - Benefit: High
  - Possible: Very challenging
  - Time: Long term
Conclusions

e-Infrastructures for M&S

- Real benefit
- Would consist of
  - Groupware
  - Grid/cloud desktop grid(s)
  - Support for simulation interoperability/distributed simulation
  - Artefact management
- Integration?
  - Grid supporting simulation interoperability… not normally found in e-Infrastructures
- Real world problems are key to understanding actual requirements
- End user/Vendor participation is absolutely required
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