Verification and Validation of Computer Simulations

POLITECHNIKA WARSZAWSKA
Wydział Inżynierii Lądowej

Weryfikacja i walidacja symulacji komputerowych

Lesław Kwaśniewski

UROCZYSTOŚĆ INAUGURACJI ROKU AKADEMICKIEGO 2013-2014

Verification and Validation of Computer Simulations

Jaka jest wiarygodność naszych symulacji komputerowych?

What are the predictive capabilities of our computer simulations?

Computational Science and Engineering (CS&E)
Computational Engineering and Physics (CE&P)

George E. P. Box

"…for many years the Journal of Applied Mechanics shunned papers on the finite element method because it was considered of no scientific substance.

T. Belytschko, W.K. Liu, B. Moran, Nonlinear Finite Elements for Continua and Structures, John Wiley & Sons, LTD, Chichester, England, 2000

„Essentially, all models are wrong, but some are useful''

Box G.E.P., Draper N.R. (1987) Empirical model-building and response surfaces, *John Wiley & Sons*., pp. 669

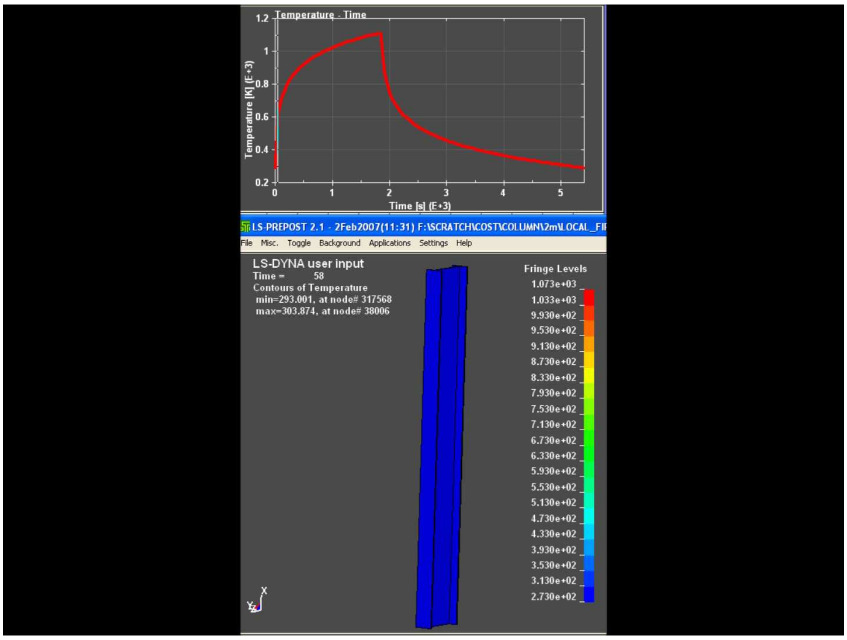
Plan for presentation

- Main question
- Spectacular examples
- Some facts
- Validation and calibration
- Predictive capabilities

- Verification & Validation
  - General aspects
  - Definitions
  - Verification
  - Validation
  - Calibration
  - SRQ
  - Validation Metrics

- Example
- Summary

Symulacje komputerowe opracowane z udziałem pracowników i studentów WIL



Spectacular example of a software bug

F-22 Squadron Shot Down by the International Date Line (2007)

Maj. Gen. Don Sheppard (ret.):

”...At the international date line, whoops, all systems dumped and when I say all systems, I mean all systems, their navigation, part of their communications, their fuel systems.

$120 million F-22 Raptor

……

It was a computer glitch in the millions of lines of code, somebody made an error in a couple lines of the code and everything goes.”

http://www.defenseindustrydaily.com

Verification and Validation of Computer Simulations

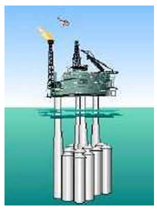
The sinking of the Sleipner A offshore platform

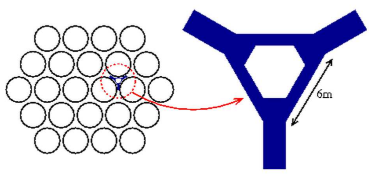
http://www.ima.umn.edu/~arnold/disasters/sleipner.html

The failure involved a total economic loss of about $700 million.

Failure in a cell wall, resulting in a serious crack and a leakage that the pumps were not able to cope with. The wall failed as a result of a combination of a serious error in the finite element analysis and insufficient anchorage of the reinforcement in a critical zone.

The post accident investigation traced the error to inaccurate finite element approximation of the linear elastic model of the tricell (using the popular finite element program NASTRAN). The shear stresses were underestimated by 47%, leading to insufficient design. In particular, certain concrete walls were not thick enough.





Some facts - hardware

„In the 1970s, a 20 ms crash test simulation using a 300-element vehicle model took about 30 hours of computer time at a cost equivalent to the three-year salary of a university professor.''

Belytschko T., Liu W. K., Moran B., Nonlinear finite elements for continua and structures, Wiley New York, 2000

TOP 10 Sites for June 2013

For more information about the sites and systems in the list, click on the links or view the complete list.

Rank	Site	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	National University of Defense Technology China	**Tianhe-2 (MilkyWay-2)** - TH-IVB-FEP Cluster, Intel Xeon E5-2692 12C 2.200GHz, TH Express-2, Intel Xeon Phi 31S1P NUDT	3,120,000	33,862.7	54,902.4	17,808
2	DOE/SC/Oak Ridge National Laboratory United States	**Titan** - Cray XK7 , Opteron 6274 16C 2.200GHz, Cray Gemini interconnect, NVIDIA K20x Cray Inc.	560,640	17,590.0	27,112.5	8,209
3	DOE/NNSA/LLNL United States	**Sequoia** - BlueGene/Q, Power BQC 16C 1.60 GHz, Custom IBM	1,572,864	17,173.2	20,132.7	7,890
4	RIKEN Advanced Institute for Computational Science (AICS) Japan	K computer, SPARC64 VIIIfx 2.0GHz, Tofu interconnect Fujitsu	705,024	10,510.0	11,280.4	12,660
5	DOE/SC/Argonne National Laboratory United States	**Mira** - BlueGene/Q, Power BQC 16C 1.60GHz, Custom IBM	786,432	8,586.6	10,066.3	3,945
6	Texas Advanced Computing Center/Univ. of Texas United States	**Stampede** - PowerEdge C8220, Xeon E5-2680 8C 2.700GHz, Infiniband FDR, Intel Xeon Phi SE10P Dell	462,462	5,168.1	8,520.1	4,510
7	Forschungszentrum Juelich (FZJ) Germany	**JUQUEEN** - BlueGene/Q, Power BQC 16C 1.600GHz, Custom Interconnect IBM	458,752	5,008.9	5,872.0	2,301
8	DOE/NNSA/LLNL United States	**Vulcan** - BlueGene/Q, Power BQC 16C 1.600GHz, Custom Interconnect IBM	393,216	4,293.3	5,033.2	1,972
9	Leibniz Rechenzentrum Germany	**SuperMUC** - iDataPlex DX360M4, Xeon E5-2680 8C 2.70GHz, Infiniband FDR IBM	147,456	2,897.0	3,185.1	3,423
10	National Supercomputing Center in Tianjin China	**Tianhe-1A** - NUDT YH MPP, Xeon X5670 6C 2.93 GHz, NVIDIA 2050 NUDT	186,368	2,566.0	4,701.0	4,040

Moore's law states that computer power increases by a factor of two every eighteen months

Verification and Validation of Computer Simulations

Some facts - software

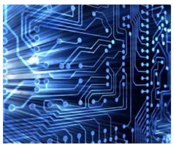
LS-DYNA® - a finite element (FE) based simulation software - had originally 50,000 lines of code and then approached 2.5 million lines recently.

Barriers to computability - smoothness and stability of the response, uncertainties, coupled physics, ...

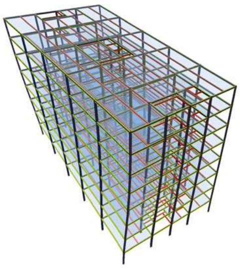
The number of execution paths in a typical commercial code is often so large that some paths are never explored, even after years of service.

Belytschko T., Mish K., "Computability in nonlinear solid mechanics"
http://www.tam.northwestern.edu/tb/computability_w_figs.pdf

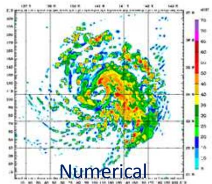
What are the predictive capabilities of our computer simulations?



Modeling electronic systems e.g. Verilog



Computational Science and Engineering (CS&E) Computational Engineering and Physics (CE&P)

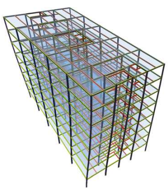


Numerical weather prediction „forecast sun is raining”

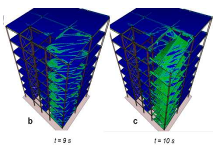
Numerical models in economics

VERY GOOD — POOR

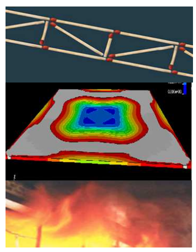
What are the predictive capabilities of our computer simulations (Computational Science and Engineering (CS&E))?



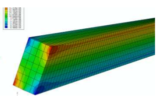
Linear FE dynamic analysis



Nonlinear static (stability)

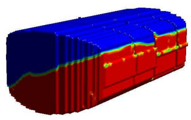


Structural Fire Engineering



Linear FE static analysis

Transient dynamics (crash tests)



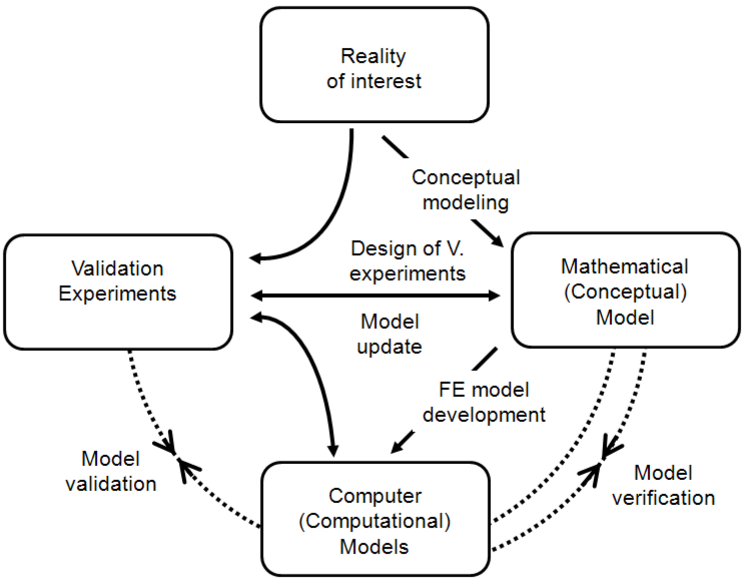
Computational Fluid Dynamics CFD

BETTER — MORE DIFFICULT

Verification & Validation

What are the recommended procedures?

General aspects of modeling, experimentation, verification, and validation



Kwasniewski L. (2009) On practical problems with verification and validation of computational models, Archives of Civil Engineering, vol. LV, no. 3, pp. 323-346.

Definitions of Verification & Validation

Verification is supposed to deliver evidence that mathematical models are properly implemented and that the numerical solution is correct with respect to the mathematical model.

Verification uses comparison of computational solutions with highly accurate (analytical or numerical) **benchmark** solutions and among themselves, whereas **validation** compares the numerical solution with the experimental data.

Verification should precede **validation.**

Experimental **validation** is the final check to reveal possible errors and to estimate the accuracy of the simulation.

Validation can be practically split into three tasks:
- to detect and separate the model's significant discrepancies,
- to remove and reduce removable and unavoidable errors,
- to evaluate uncertainties in the results.

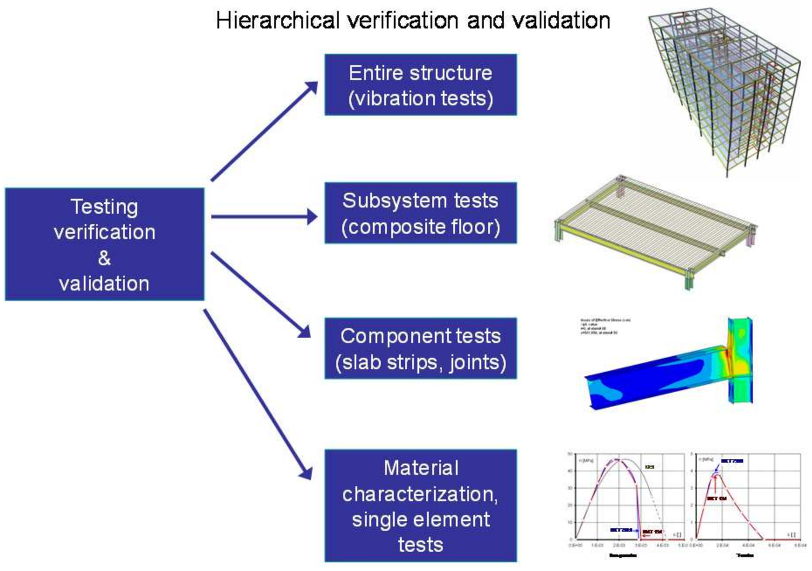
„**Verification** deals with **mathematics**; **validation** deals with **physics**''

Roache P.J. (1998) Verification and validation in computational science and engineering, Hermosa Publishers Albuquerque, NM

Validation

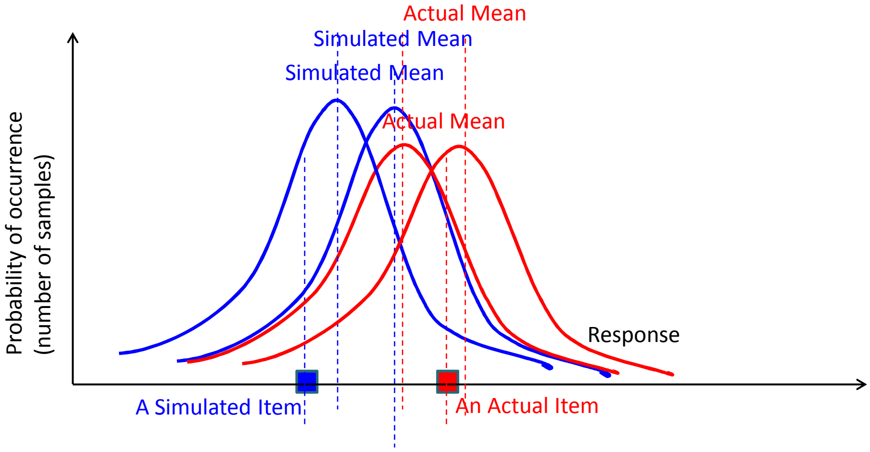
Validation hierarchy

the experiments for the considered system are usually divided into three or four levels (tiers) representing different degrees of complexity.



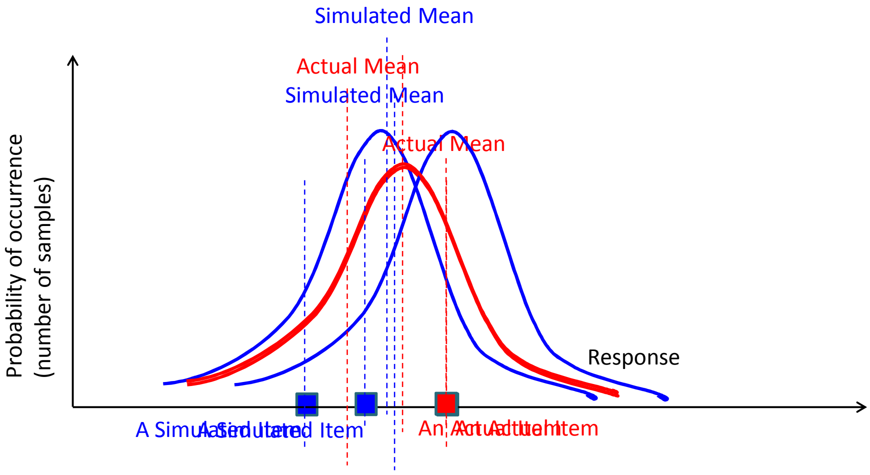
Verification and Validation of Computer Simulations

Validation and calibration



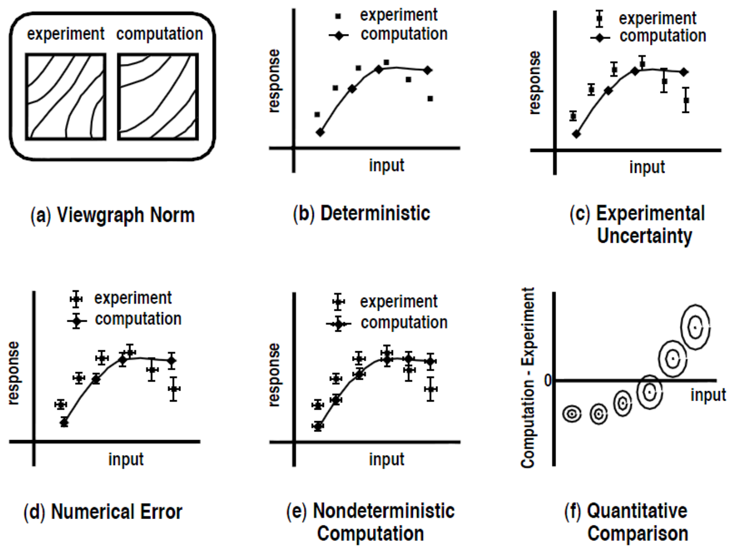
Verification and Validation of Computer Simulations

Validation and calibration



Verification and Validation of Computer Simulations

Validation Metrics



W.L. Oberkampf, T.G. Trucano, C. Hirsch, Verification, validation, and predictive capability in computational engineering and physics, Appl. Mech. Rev. 57 (5), 345–384, 2004.

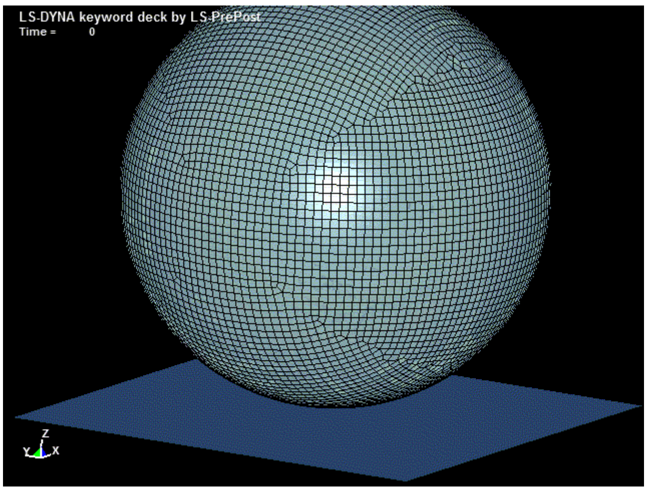
Verification and Validation of Computer Simulations

System response quantity SRQ

Validation is based on the comparison between computational results and experimental data.

An experiment can provide much less information than the calculation.

Selection of the system response quantity (SRQ) is often limited by the experiment output.

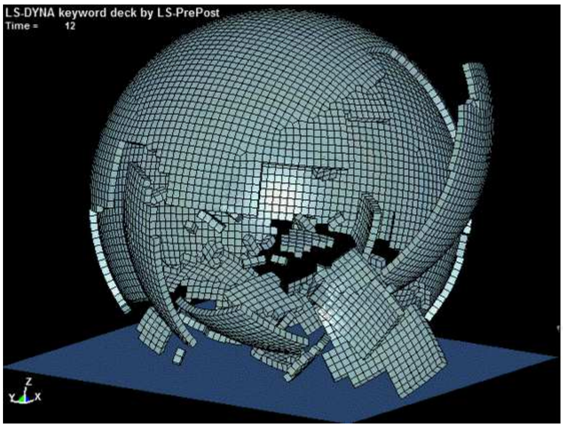


A hollow glass ball with external radius of 25mm and the wall 1mm thick is falling under gravity from a prescribed height (2.0 m) and hits a rigid surface.

System response quantity SRQ

Selection of SRQ:

1. Failure (1) or no failure (0)
2. Vertical z coordinate of Cenetr of Mass (static position)
3. Horizontal x y coordinates of Cenetr of Mass (static position)
4. Shape, mass, position of all pieces (static position).



Summary

- For the non-linear problems there are unavoidable errors that are an inherent part of the solution procedures.
- Separation of all sources of errors is today impossible for many complex systems.
- Verification through the testing of different solution options is necessary.
- For the wide range of conditions found in practice, it is impossible to define general requirements guaranteeing satisfying accuracy.

Thank you for your attention!