C7790 Introduction to Molecular Modelling

TSM Modelling Molecular Structures

C9087 Computational Chemistry for Structural Biology

Lesson 1

Computational Chemistry (Molecular Modelling)

PS/2022 Present Form of Teaching: Rev4

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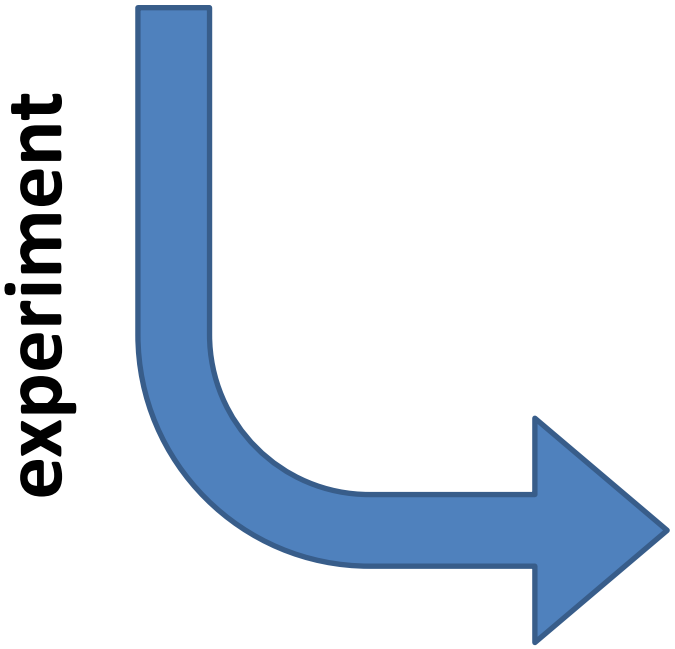
Computational chemistry

(bio)chemical problem
(behavior of the chemical system at the macroscopic level)

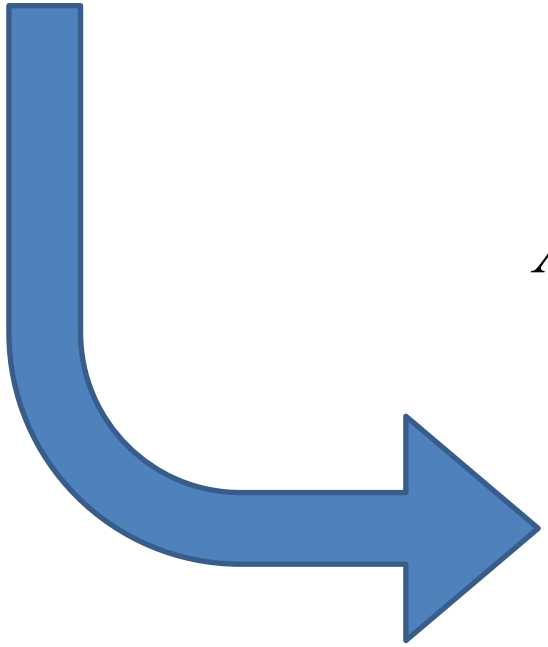


molecular nature
(behavior of the chemical system at the microscopic level)

Computational chemistry

(bio) chemical problem
(behavior of the chemical system at the macroscopic level)

experiment



$$A = -k_b T \ln \sum_k e^{-\frac{U_k}{k_b T}}$$

and more ....

molecular nature
(behavior of the chemical system at the microscopic level)

$$\hat{H}\psi_k(\mathbf{r}) = E_k\psi_k(\mathbf{r}) \qquad m_i \frac{d^2 r_i}{dt^2} = -\frac{\partial V(\mathbf{R})}{\partial r_i}$$

Computational chemistry

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(behavior of the chemical system at the macroscopic level)

experiment

calculation/simulation

?

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Reality *vs* Simulation

Is it possible to accurately simulate the reality around us?

Task I

Is it possible to accurately simulate the reality around us?

How many molecules does 180 mL of water contain at room temperature?

How much computer memory will be needed to store the position information of all atoms, including their velocities, using real numbers with single precision?

single precision real number = 4 Bytes

Task II

Is it possible to accurately simulate the reality around us?

How much machine time does 1 s long simulation with the development of the molecular system (H_2O) take?

- The fastest molecular motion in H_2O is the vibration of OH bonds.
- What is the period of this vibration (Use NIST Chemistry WebBook)?
- Each period needs to be discretized by at least 10 frames (snapshots) (see Molecular Dynamics later).
- Computation of each frame takes approximately 1 ms of computer time.

Solution

Task I (180 mL H_2O)

$N_{WAT} \approx 6x10^{24}$

$N_{mem} \approx 432\ 000\ 000\ 000\ 000\ 000\ 000\ 000\ 000\ B$

Task II (1s long simulation of H_2O)

$\tilde{v} = 3756\ cm^{-1}$ $\quad v = 113\ THz$ $\quad T = 8.8\ fs \approx 10\ fs$

$t \approx 10^{12}\ s =$ 31 709 years

Reality *vs* Simulation

Is it possible to accurately simulate the reality around us?

Unfortunately, no :-(

Why?

- incomplete theory
- insufficient performance of current and future (?) computers

Solution ...

- use **approximation** for solution of problems using the available computing capacity

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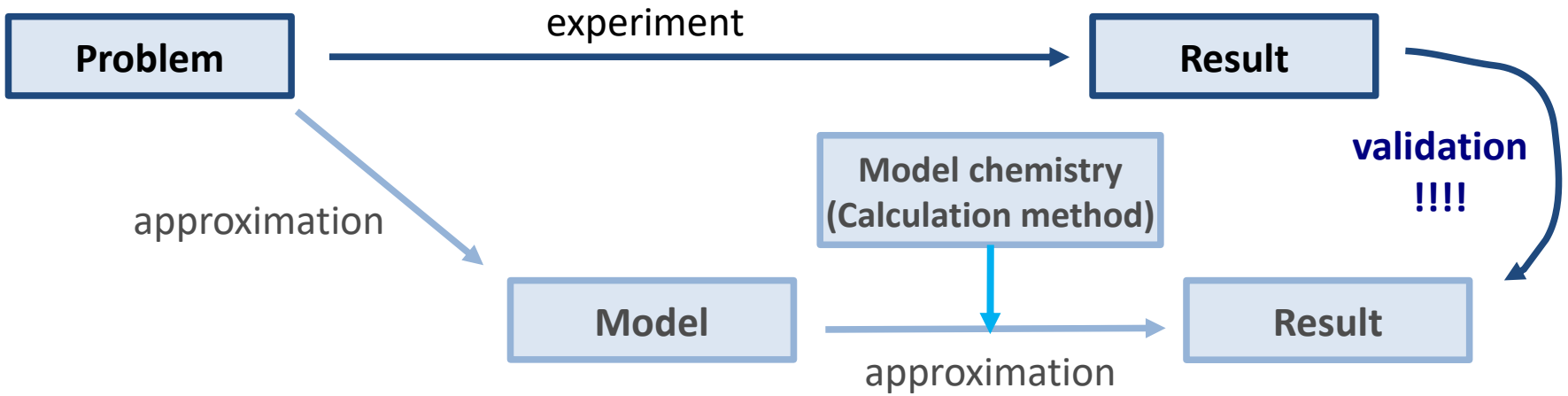

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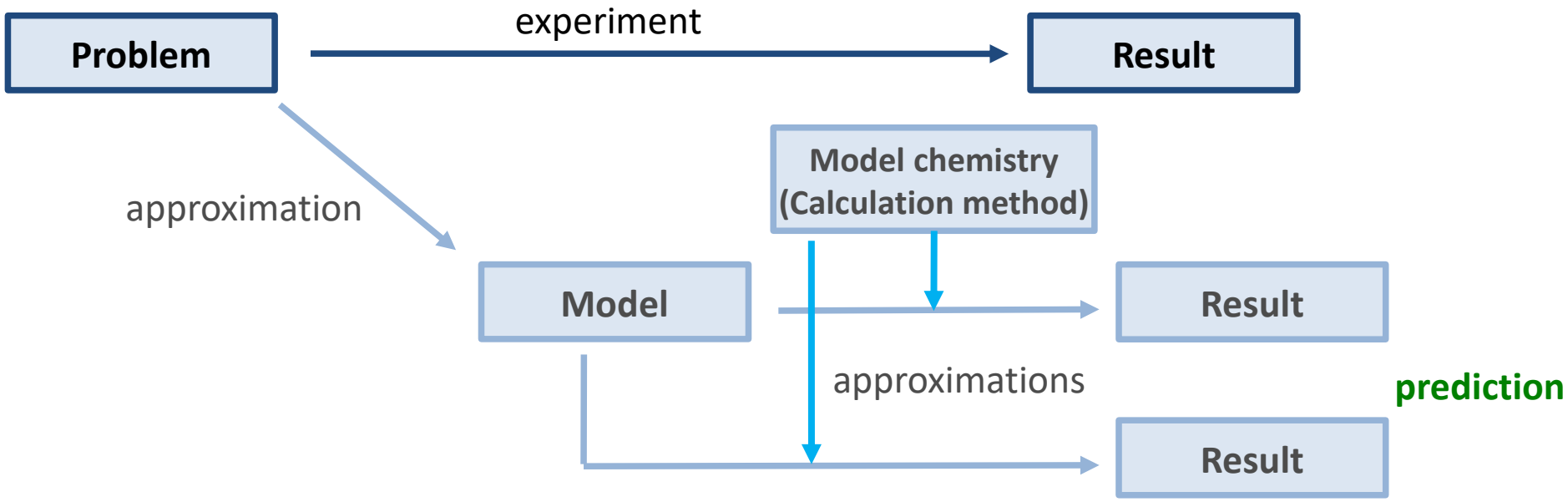


Experimental sources for validation

Comparison of predicted structures with experimental structures

- 3D structure (X-ray, docking)
- shape (cryogenic electron microscopy)
- geometric parameters
- distances (NMR)
- radial distribution function (X-ray scattering, neutron scattering)

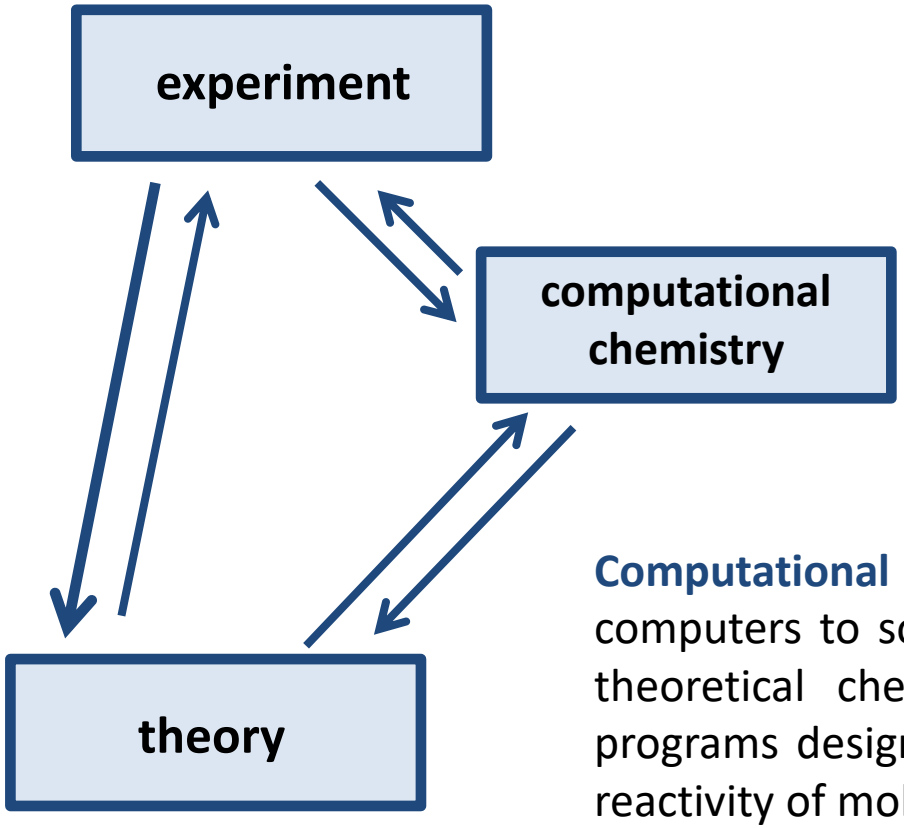
Properties of molecules

- electron spectra (UV/VIS spectroscopy)
- vibrational spectra (IR spectroscopy)
- dipole moment
- diffusion coefficient
- chemical shifts, spin-spin interaction constants (NMR)

Comparison of calculated and experimental thermodynamic and kinetic data

- enthalpy (isothermal titration calorimetry - ITC)
- entropy (ITC)
- free energy (Gibbs, Helmholtz) (ITC, kinetic measurements)

Computational chemistry



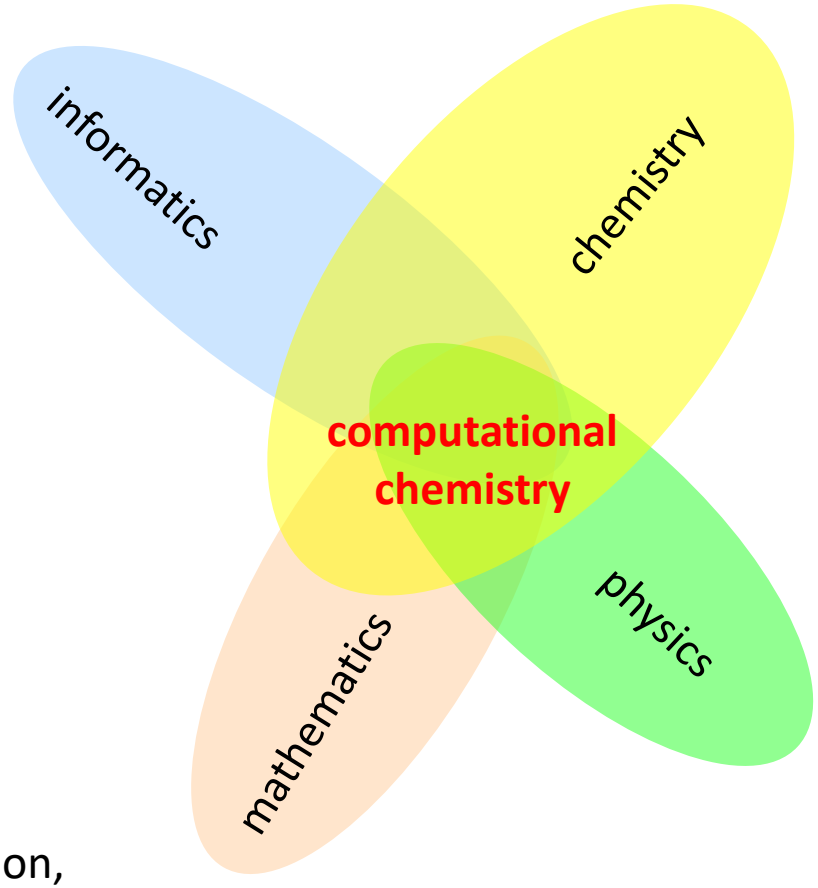
Computational chemistry is a branch of chemistry that uses computers to solve chemical problems. It uses the results of theoretical chemistry implemented in powerful computer programs designed to calculate the structure, properties and reactivity of molecules and solids.

http: // www.wikipedia.org

Multidisciplinary discipline

algorithms, CPU / GPU, cluster / grid, symbolic calculations

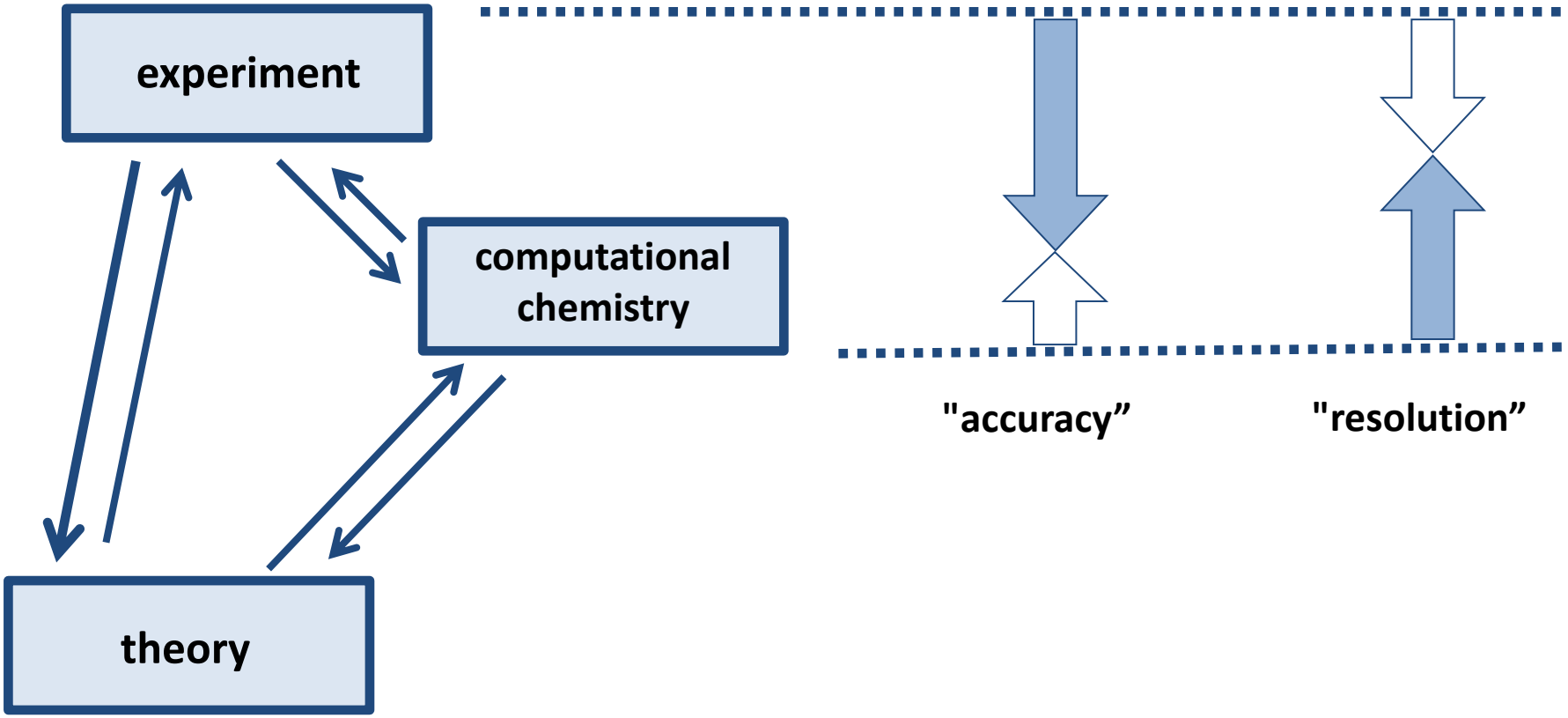
(bio)chemical problems, experiments, verification



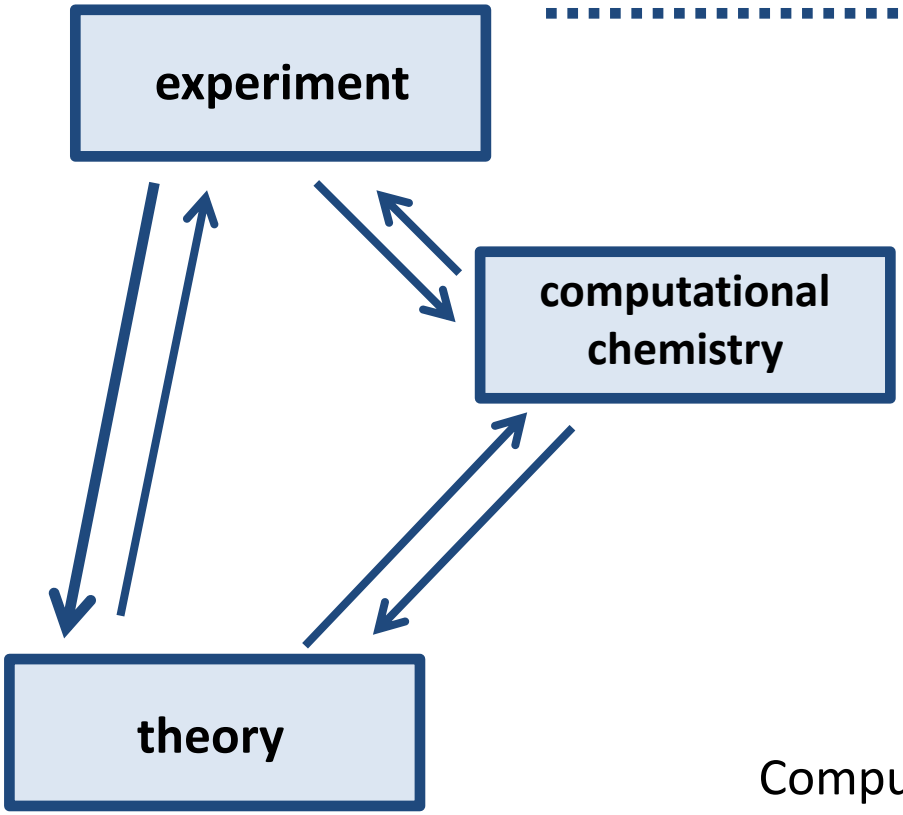
theory, approximation

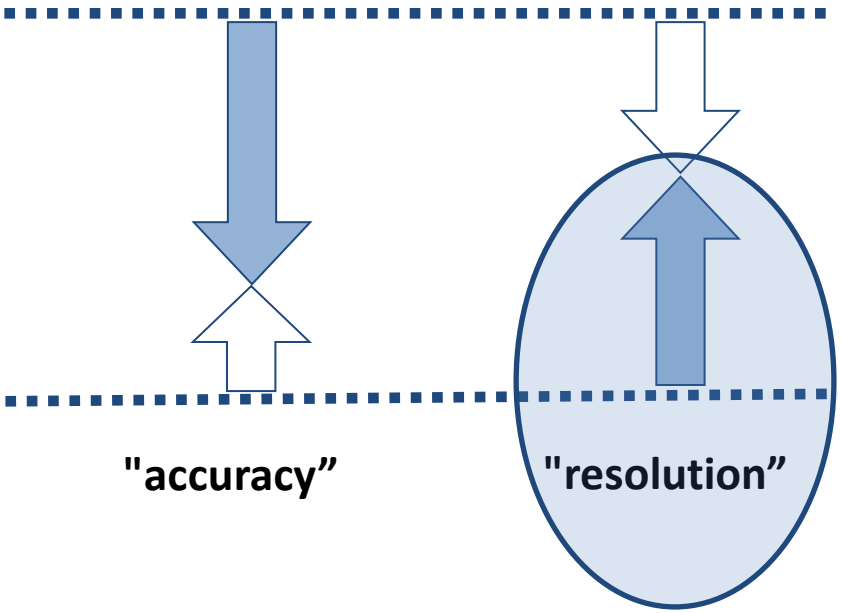
analytical solution, numerical solutions, approximation

Importance of computational chemistry



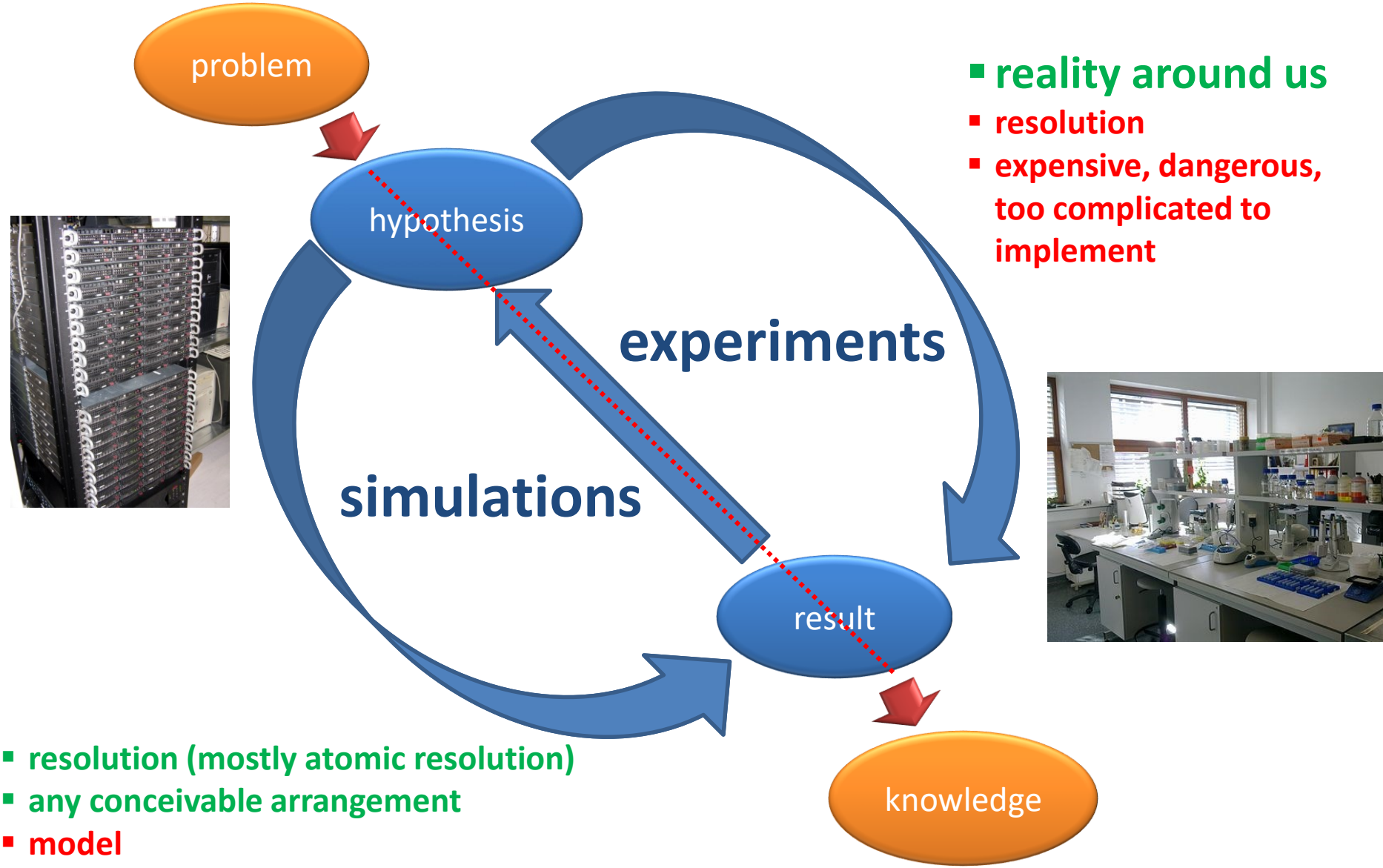
Importance of computational chemistry





Computational chemistry can work with **single atom resolution**.

Experiment vs simulation



- reality around us
- resolution
- expensive, dangerous, too complicated to implement

- resolution (mostly atomic resolution)
- any conceivable arrangement
- model

Summary

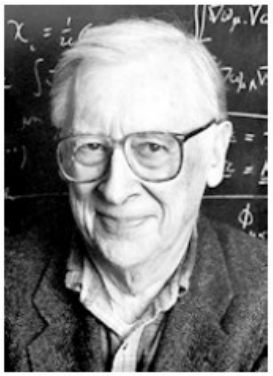
Computational chemistry (molecular modelling):

- it is an **interdisciplinary** scientific discipline combining current knowledge of physics, chemistry, mathematics and computer sciences for computational study of **structure, properties, and reactivity** molecular systems
- it uses **approximate** models and calculation procedures
- it requires **verification/calibration** of employed models and computational procedures against experimental data
- it can reach both **qualitative (mostly) and quantitative** results (according to models used)
- it typically employs models with **atomic resolution**

During the lecture we will get acquainted with methods enabling the study of systems containing up to **1,000,000 atoms** in the time scale **a few microseconds**.

Nobel Prize in Chemistry 1998/2013

Walter Kohn



John A. Pople

© Harvard University

Martin Karplus

Photo: © S. Fisch

Michael Levitt

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Arieh Warshel

The Nobel Prize in Chemistry 1998 was divided equally between

Walter Kohn for his development of the **density-functional theory** and

John A. Pople for his development of **computational methods in quantum chemistry**

Development of Multiscale Models for Complex Chemical Systems

http://www.nobelprize.org/nobel_prizes/chemistry/laureates/1998/
http://www.nobelprize.org/nobel_prizes/chemistry/laureates/2013/