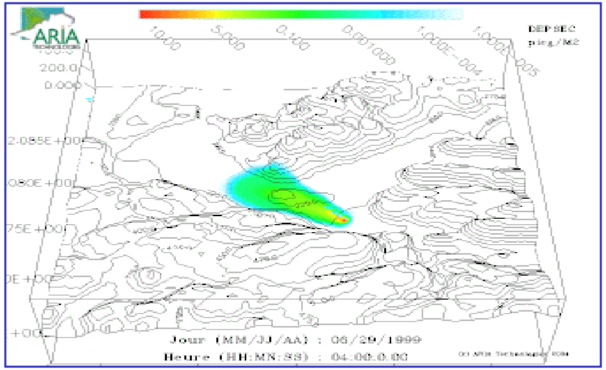
What are scientific models? Part I

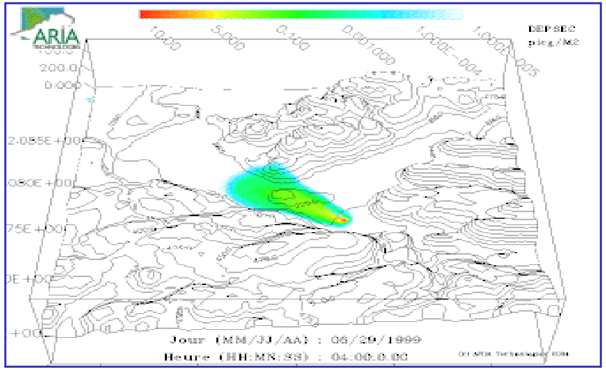
Some Examples

Some Examples

Some Examples



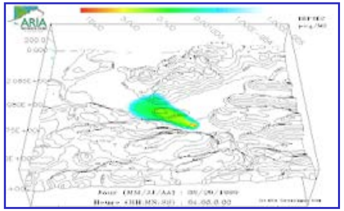
Some Examples



$P_d = a - b\ Q_d$	(demand function)
$P_s = c + d\ Q_s$	(supply function)
$Q_d = Q_s$	(market equilibrium)
$P_d = P_s + T$	(Transaction cost mark-up)

Some Examples

Stands in for...



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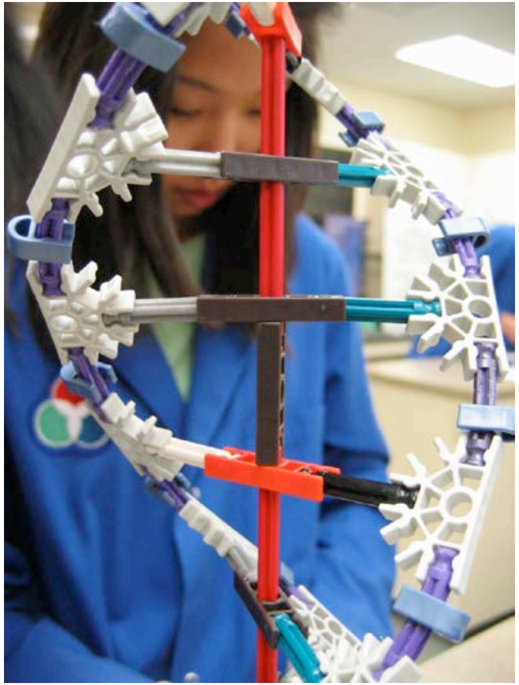
What is the Nature of Models?

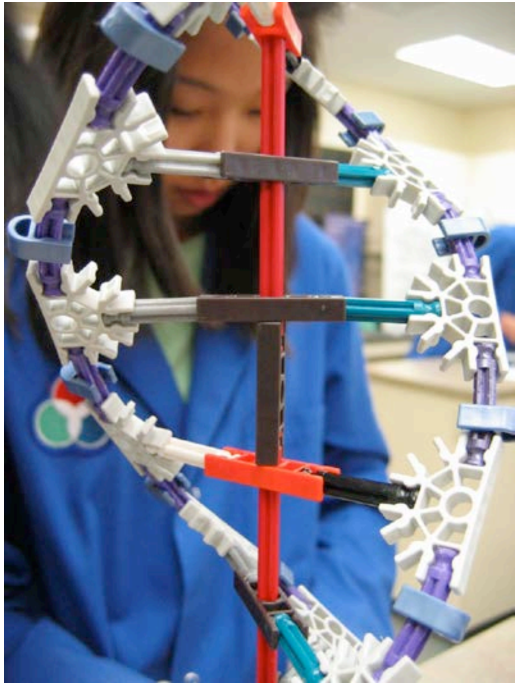
Models as…

- representations
- idealisations
- purpose-dependent
- things to manipulate

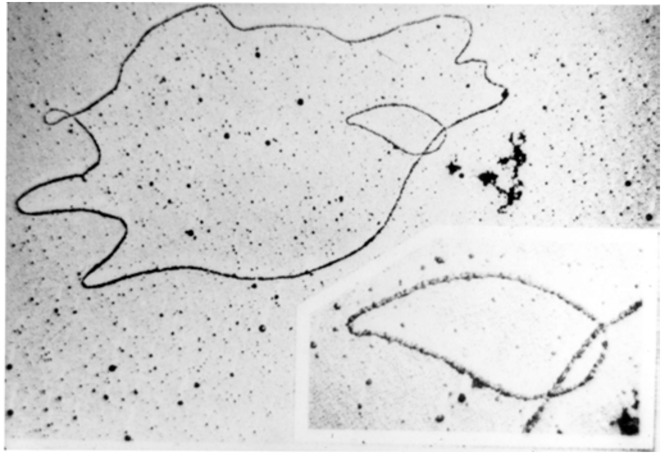
Models as Representations



Models as Representations

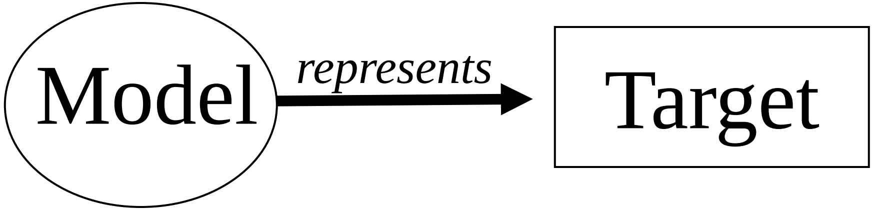


Stands in for



Models as Representations

Models as Representations



CONCEPTEST 1

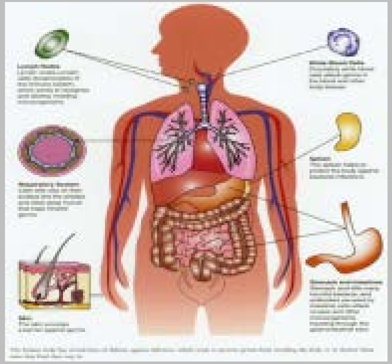
Why represent targets with models, instead of investigating the target itself?

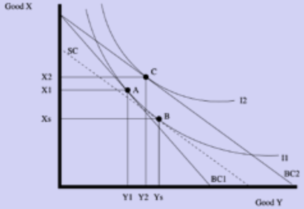
Write down your answer in two sentences, before continuing!

Why Use Models?

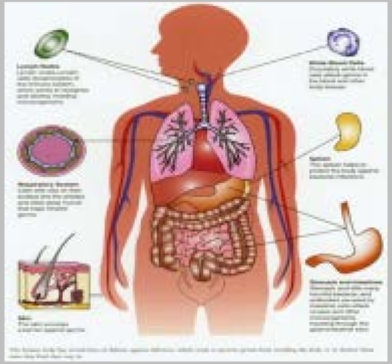
Why Use Models?

Why Use Models?





Models as Idealisations



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What are scientific models? Part II

Why Use Models?

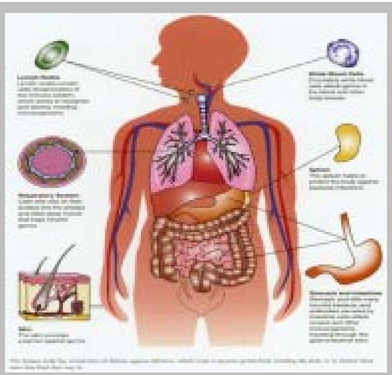
Investigating the target directly would be….

…physically impossible or too costly

…legally or morally prohibited

…cognitively too demanding, so that instead we investigate a simplified model

Models as Idealisations



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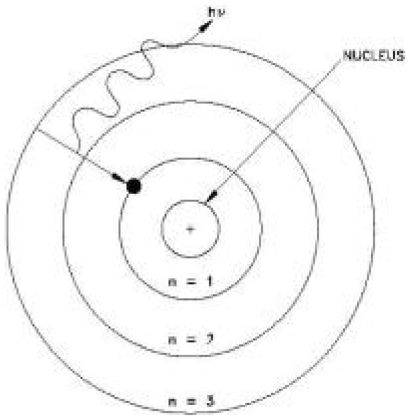

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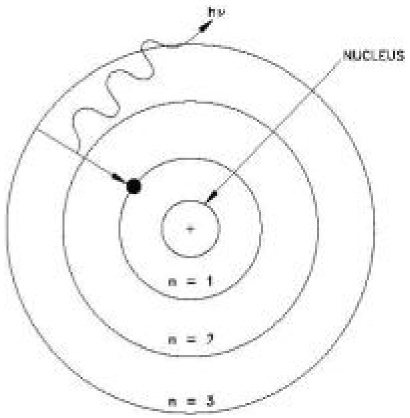
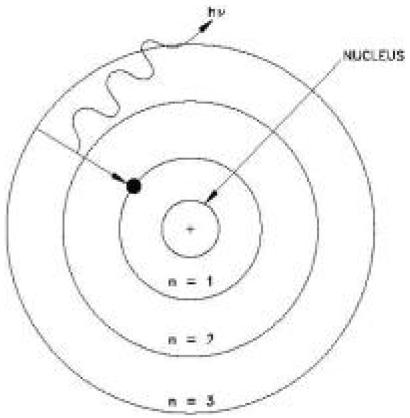


"Bohr Theory" (1913)

•*One has reasons to believe that theory is not false*

•*Object of theory is indeed governed by principles stated in theory*

Models as Idealisations



“Bohr Theory” (1913) → *“Bohr Model” (1925)*

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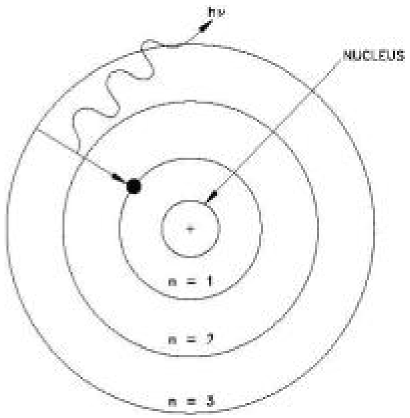
- *Provides approximation of object in question*
- *Alternative representations of the same object useful for other purposes exist*

Models are Purpose-Dependent



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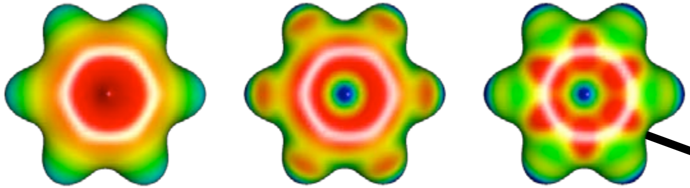
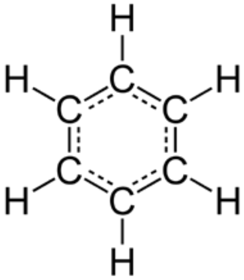
Models are Purpose-Dependent

Same target, two different models



true electrostatic potential based on quantum mechanically derived molecular orbitals of benzene

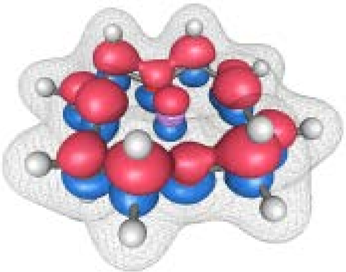


structural formula of benzene

chemical compound

Models are Purpose-Dependent

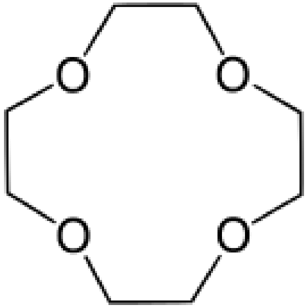
Same target, two different models



Quantum mechanical model of a chemical compound

- more precise
- more similar in relevant properties

chemical compound

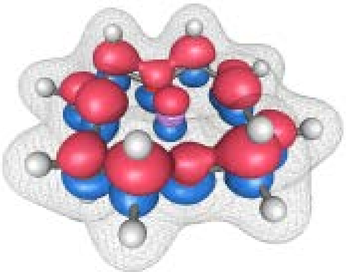


structural formula of a chemical compound

- simpler
- more transparent
- theoretically more tractable (functional group analysis!)

Models are Purpose-Dependent

Same target, two different models



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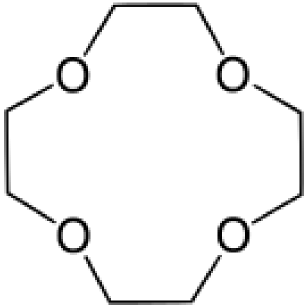

structural formula of a chemical compound

- simpler
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chemical compound

Which model is better?

Answer depends on **purpose**.

Module II: Models & Modelling

Video 3

Till Grüne-Yanoff

KUNGL TEKNISKA HÖGSKOLAN

What is the Nature of Models?

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Models as…

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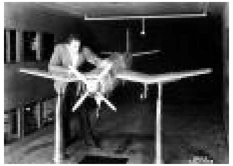
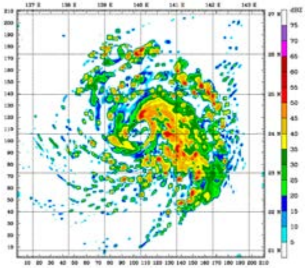
Material Models

Material Models

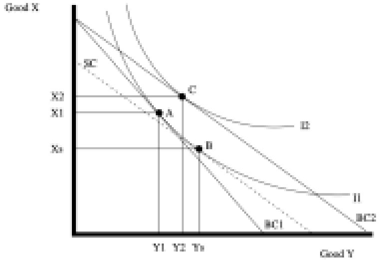
Material, Computational & Mathematical Models



Material models



Computational models



$$Q_d = Q_s$$

$$Q_d = a - bP$$

$$Q_s = -c + dP$$

Mathematical models

Material Models

https://www.youtube.com/watch?v=q_eMQvDoDWk

3:28 – 3:38

Material Models

https://www.youtube.com/watch?v=q_eMQ
vDoDWk

3:28 – 3:38

http://www.procedureswithcare.org.uk/subc
utaneous-injection-in-the-rat/

1:44-1:49

Learning By Manipulating Models

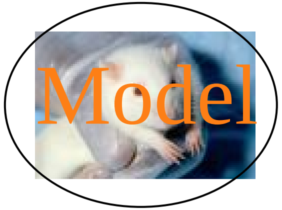
Peter Mennim, “Portrait of an Academic [Mary Hesse (1924–2016)]”

Learning By Manipulating Models

Organs
Physiology
Nervous systems
Hormones

Positive ⟷ *analogy*

Organs
Physiology
Nervous systems
Hormones



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Learning By Manipulating Models

Organs
Physiology
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Positive analogy

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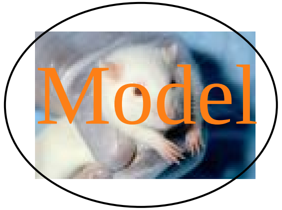

Size
Lifespan
Gestation period

Negative analogy

Size
Lifespan
Gestation period

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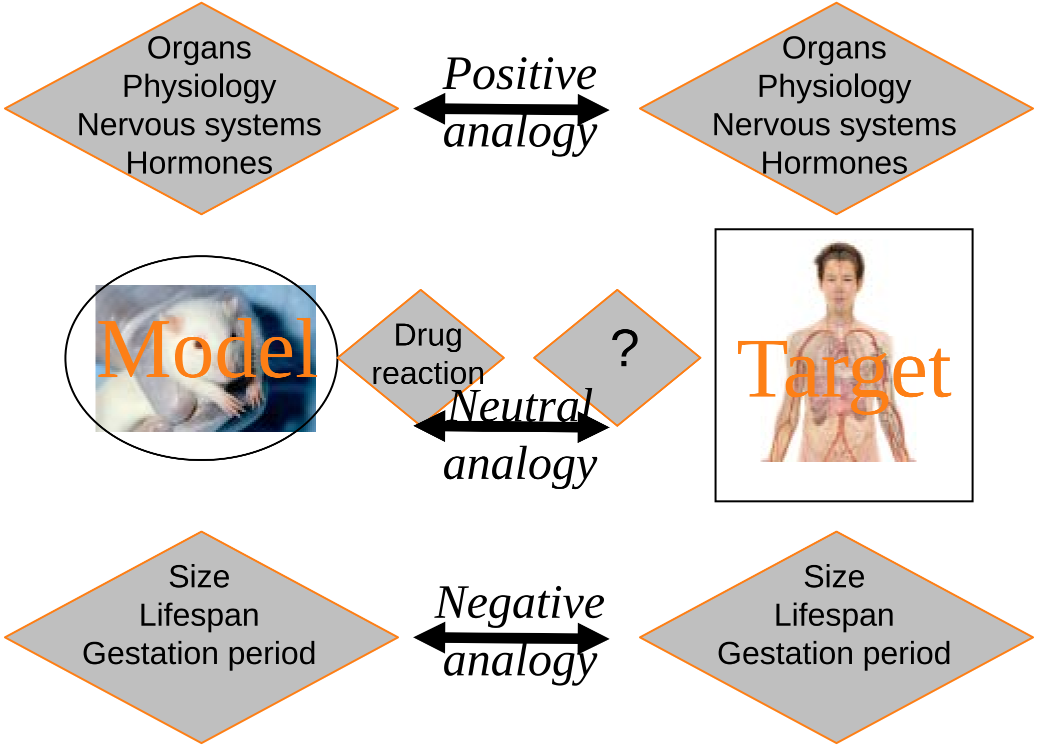
Learning By Manipulating Models



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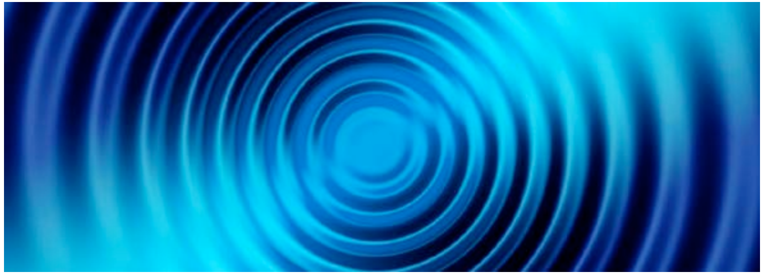
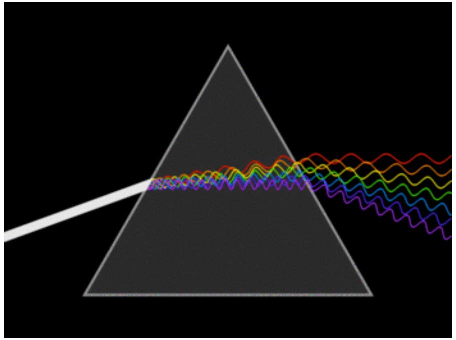
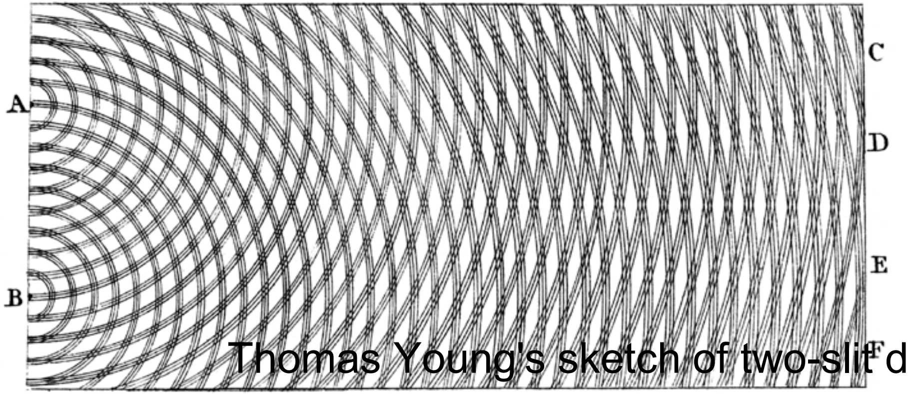
Learning By Manipulating Models

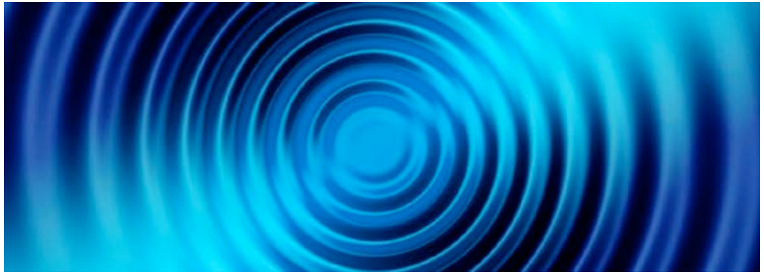


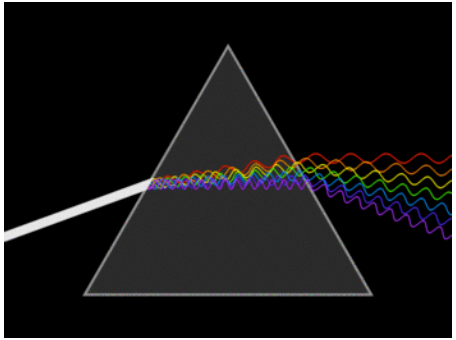


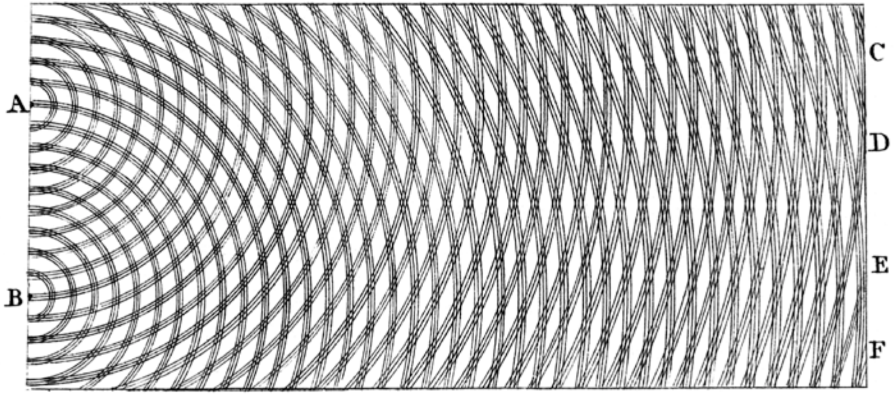


Thomas Young's sketch of two-slit diffraction, which he presented to the Royal Society in 1803.

Learning By Manipulating Models







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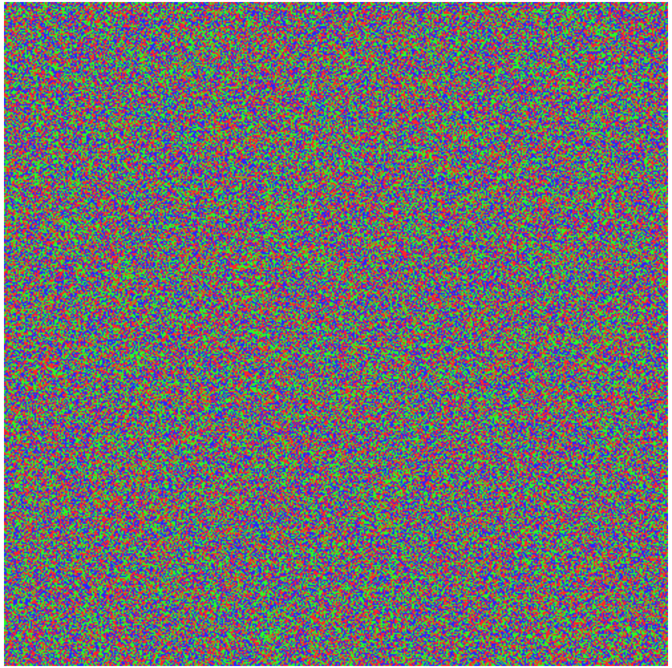


Models vs. Experiments

Similarities

- In a model, we set variables & parameters – *cf. experimental control*
- We manipulate a model – *cf. experimental manipulation*
- We observe results of model manipulation – *cf. exp. Observation*

Models vs. Experiments

Similarities

- In a model, we set variables & parameters – *cf. experimental control*
- We manipulate a model – *cf. experimental manipulation*
- We observe results of model manipulation – *cf. exp. observation*

Differences

- *Internal validity* less of a problem for models than for experiments
- *External validity* a problem for *all* models but only for *some* experiments

Models vs. Experiments

- Models are things to manipulate
- Afford neutral analogies
- Source of errors distinguishes modelling from experimenting.

Model virtues: what makes a good model?

Part I: Similarity

What Makes a Good Model?

No fixed scheme…but many ingredients that need to be balanced:

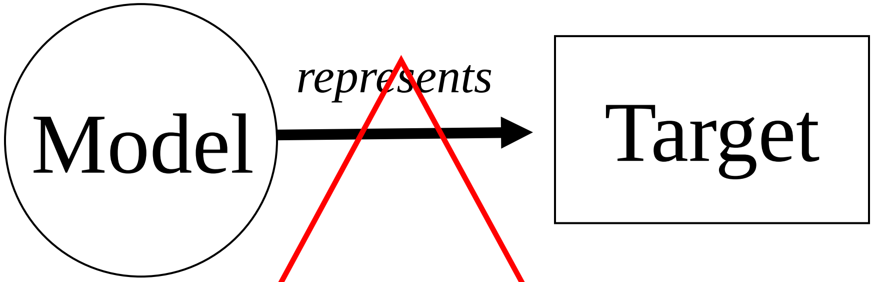
- Similarity to target
- Robustness
- Precision
- Simplicity
- Theoretical tractability
- Transparency

Similarity

$$\text{Model} \xrightarrow{\textit{represents}} \text{Target}$$

$$\xrightarrow{\textit{… is similar to…}}$$

Similarity



A model M is a good representation of a target X if and only if *M* is similar to *X* with respect to properties *P* to the degree d^P.

According to the above definition, can we ever exclude *any* model as a bad representation of any given target?

Think about this for a moment and formulate your answer in a sentence or two.

Similarity

… is similar to…

Material properties:

Model fuselage made of plastic

...

Airplane exterior hull made of metal

...

Geometric properties

laminar flow inverted gull wing

...

laminar flow inverted gull wing

...

Interior design properties

Model has no interior elements

two seats, covered in leather, ...

Model virtues: what makes a good model?

Part II

What Makes a Good Model?

Many ingredients that need to be balanced:

- Similarity to target
- Robustness
- Precision
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- Theoretical tractability
- Transparency

Robustness

A model result is **robust** (with respect to some condition Cond 2) if changing this condition does not change the model result

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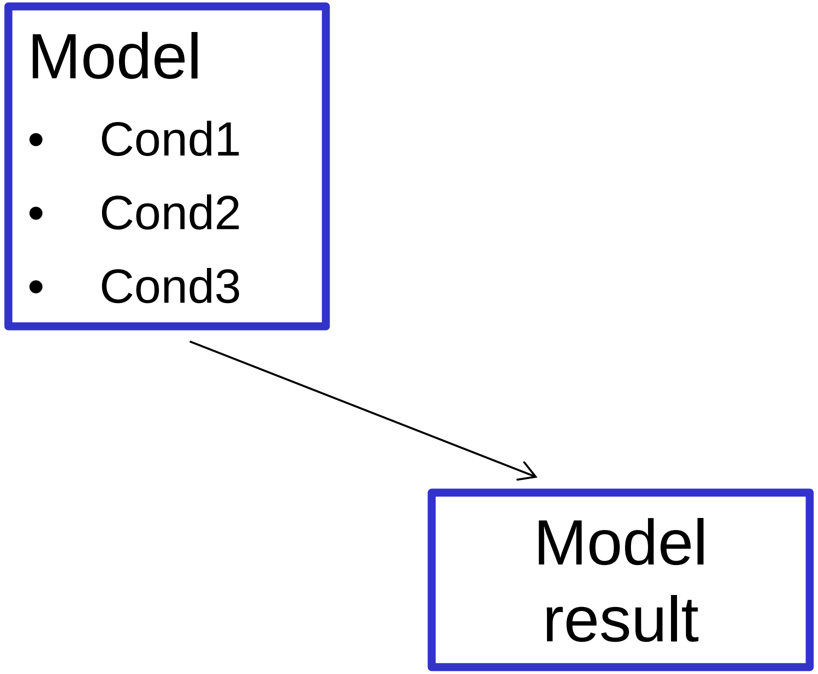

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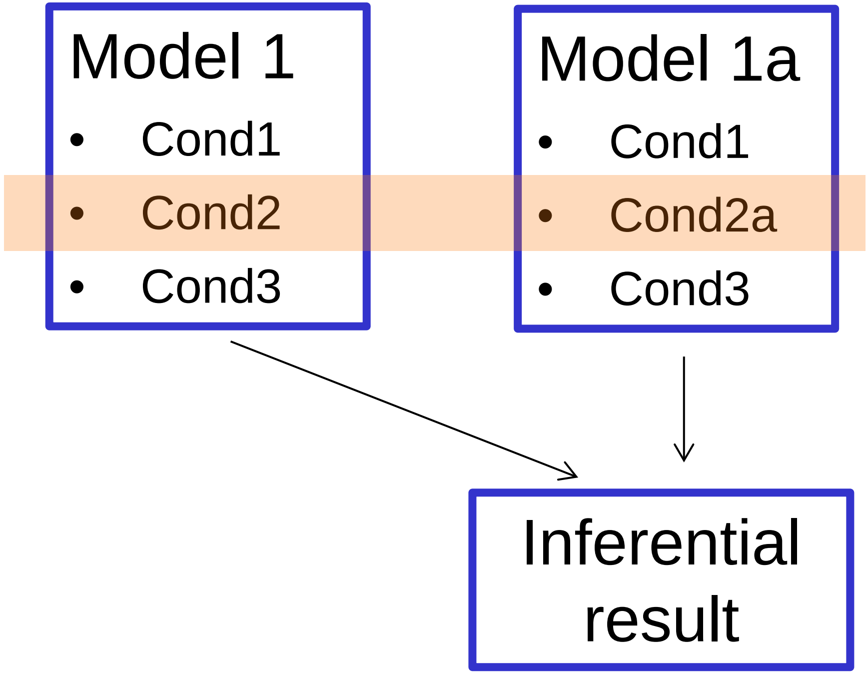

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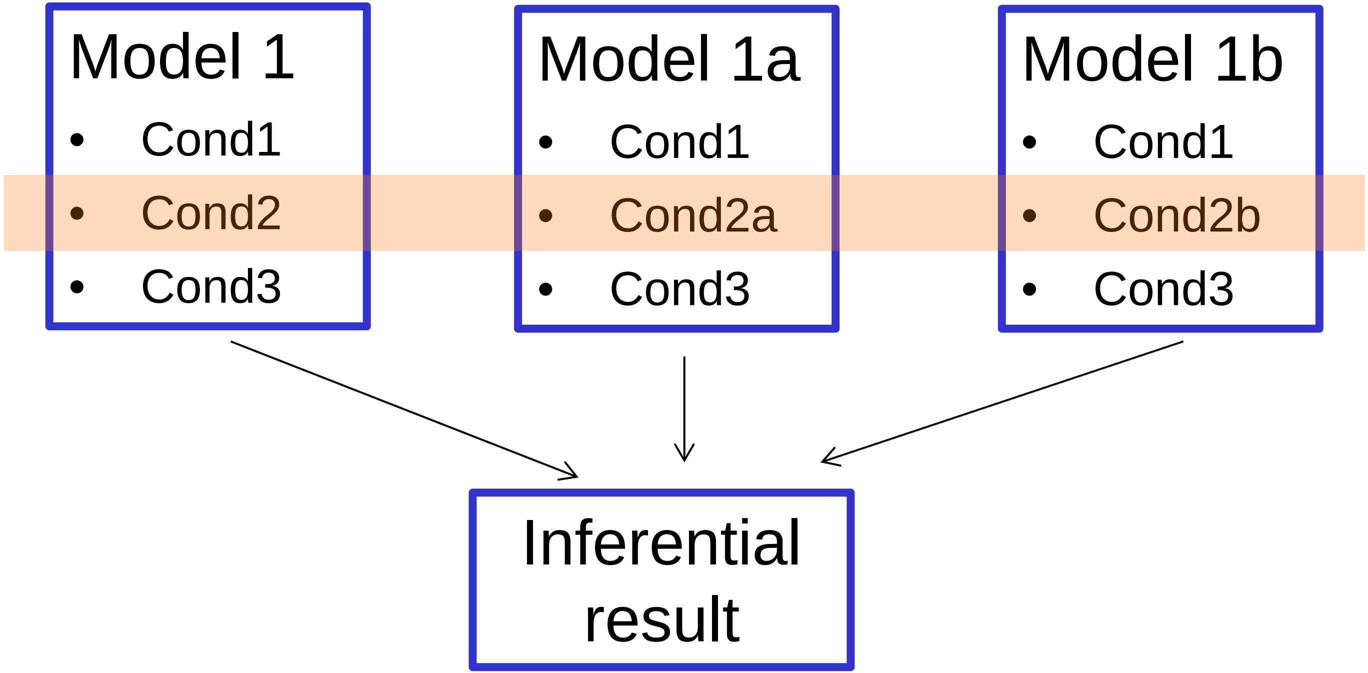

Precision

A model M1 is **more precise (**with respect to a parameter P) than another model M2 if the parameter specifications of M1 imply the parameter specifications of M2

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M1: $dN/dt = f(N)$

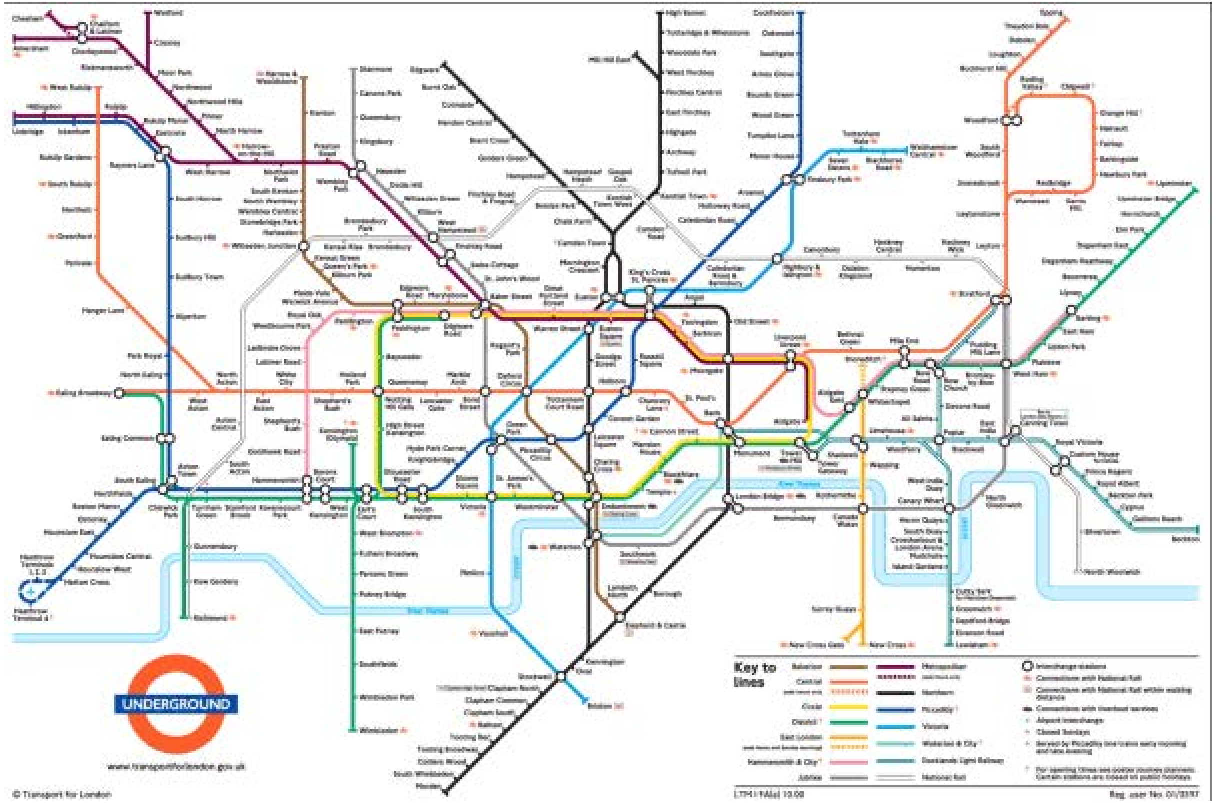
M2: $dN/dt = rN$

M3: $dN/dt = 1.5N$

Direction of implication

Simplicity

Simplicity



Simplicity

A model M1 is **simpler** than another model M2 if (i) M1 processes less variables than M2, (ii) M1 contains less parameters than M2, and (iii) M1 uses fewer operations than M2.

Tractability

A model is **tractable** (with respect to some general set of rules), if the relevant model result can be obtained by applying these principles to the model.

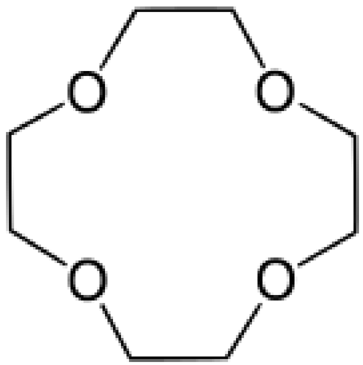
Theoretical Tractability

Theory

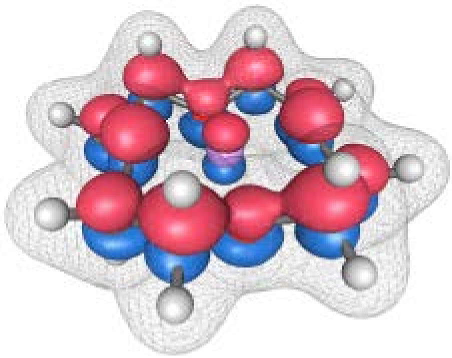
Group Classification

Dynamic/relational properties

Model



structural formula of a chemical compound



Quantum mechanical model of a chemical compound

Transparency

A model is **epistemically transparent** if the model user is cognitively capable of understanding how the model result is produced

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Transparent

Ax. 1.	$\{P(\varphi) \wedge \Box\, \forall x[\varphi(x) \to \psi(x)]\} \to P(\psi)$
Ax. 2.	$P(\neg\varphi) \leftrightarrow \neg P(\varphi)$
Th. 1.	$P(\varphi) \to \Diamond\, \exists x[\varphi(x)]$
Df. 1.	$G(x) \iff \forall\varphi[P(\varphi) \to \varphi(x)]$
Ax. 3.	$P(G)$
Th. 2.	$\Diamond\, \exists x\, G(x)$
Df. 2.	$\varphi \text{ ess } x \iff \varphi(x) \wedge \forall\psi\, \{\psi(x) \to \Box\, \forall y[\varphi(y) \to \psi(y)]\}$
Ax. 4.	$P(\varphi) \to \Box\, P(\varphi)$
Th. 3.	$G(x) \to G \text{ ess } x$
Df. 3.	$E(x) \iff \forall\varphi[\varphi \text{ ess } x \to \Box\, \exists y\, \varphi(y)]$
Ax. 5.	$P(E)$
Th. 4.	$\Box\, \exists x\, G(x)$

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Th. 4.	$\Box\, \exists x\, G(x)$

Not Transparent

"A network consisting of 1.73 billion nerve cells connected by 10.4 trillion synapses… The process took 40 minutes to complete the simulation of 1 second of neuronal network activity in real, biological, time….."

What Makes a Good Model?

Many ingredients that need to be balanced:

- Similarity to target
- Robustness
- Precision
- Simplicity
- Theoretical tractability
- Transparency

Trading off Virtues

Increasing one epistemic virtue in a model often means decreasing another one

e.g.: precision --- transparency

similarity --- simplicity

Building a model means finding the trade-off best for your purpose!

Module II: Models & Modelling

Video 5

Till Grüne-Yanoff

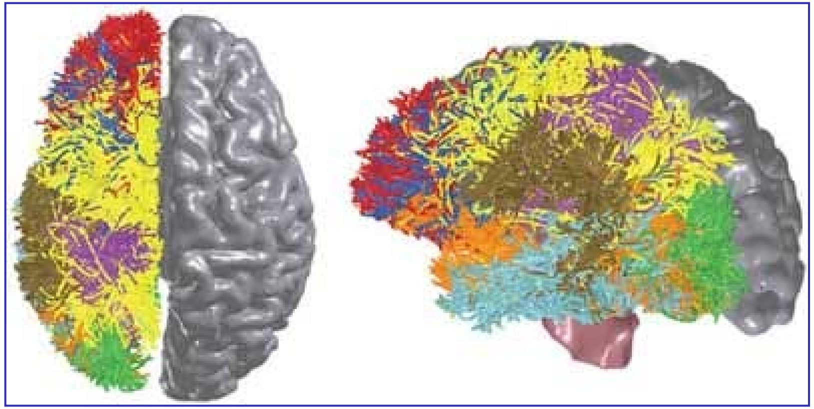
Kungl Tekniska Högskolan

Learning from models

Learning from and with Models

- as **mirrors** of the real world
- as **isolations**

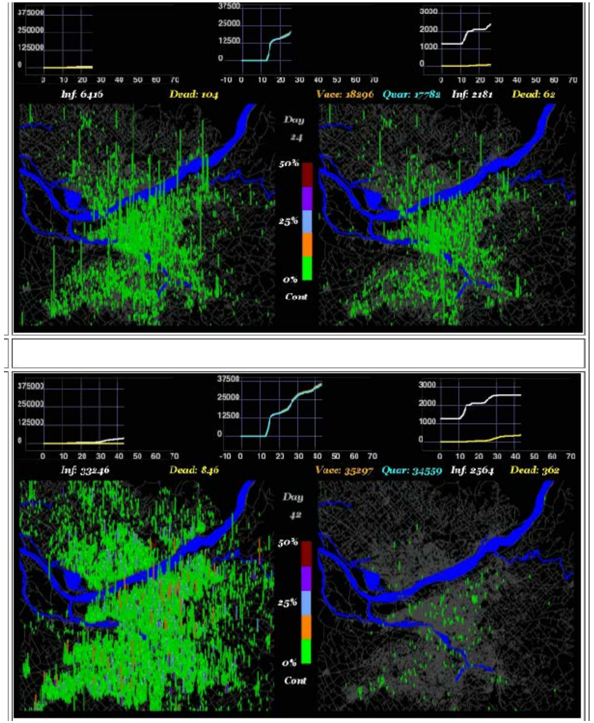
Models as Mirrors

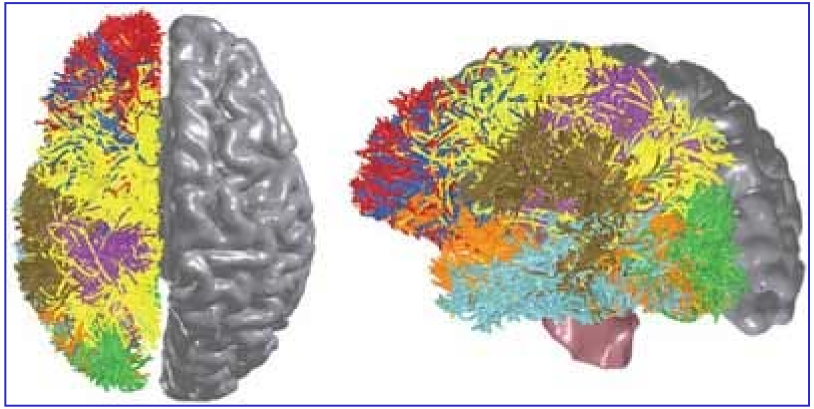


Largest neuronal network simulation, using K computer, RIKEN 2013

Models as Mirrors

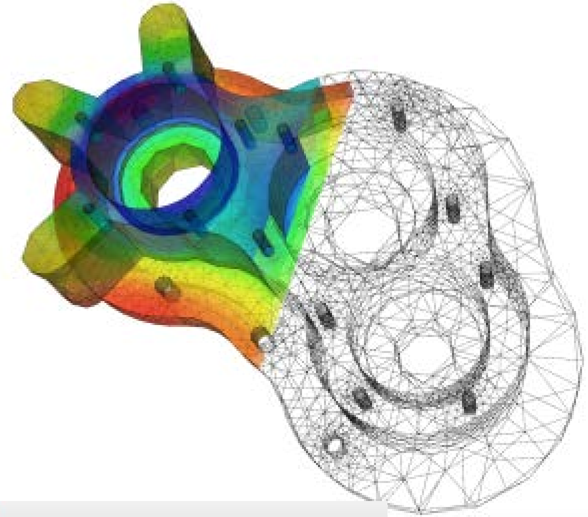
Simulation of smallpox epidemic, Portland, OR. *Nature* 2004.



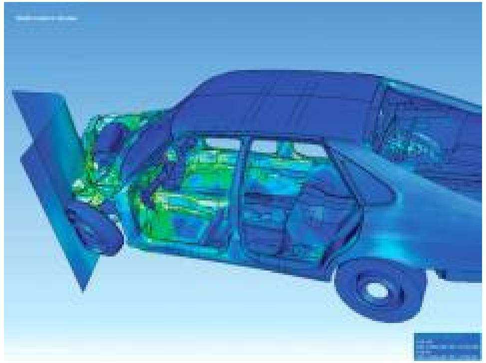


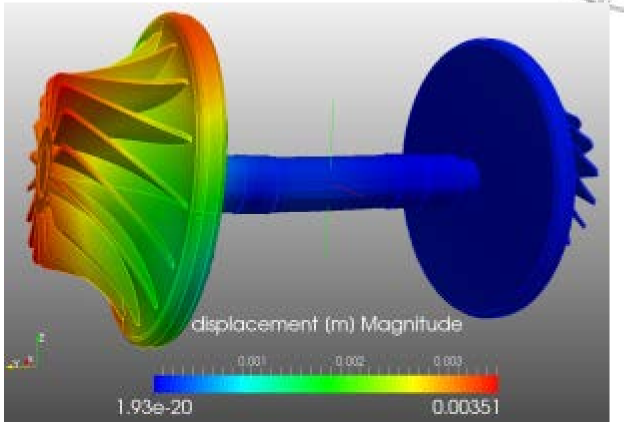
Largest neuronal network simulation, using K computer, RIKEN 2013

Models as Mirrors: FE Analysis

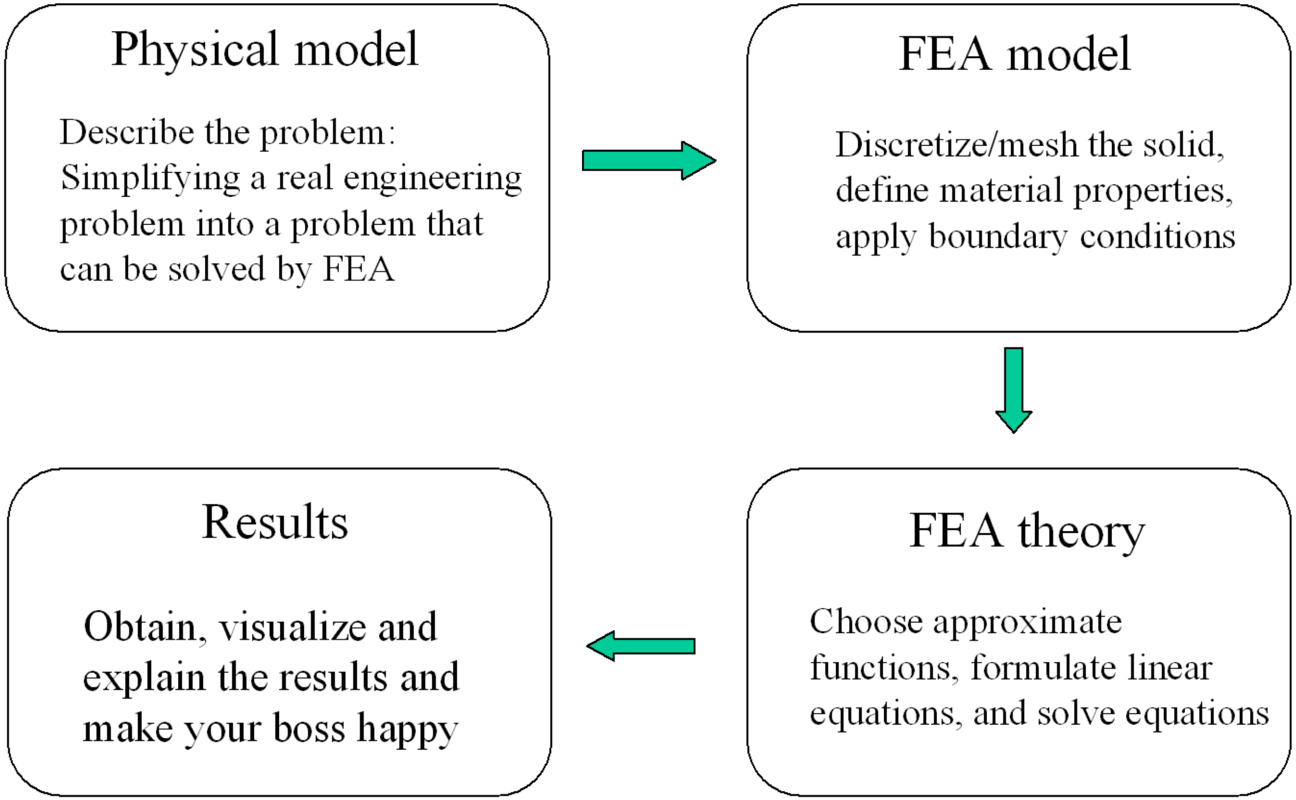


Finite element simulation of impact damages on car (left) and bridge (below)



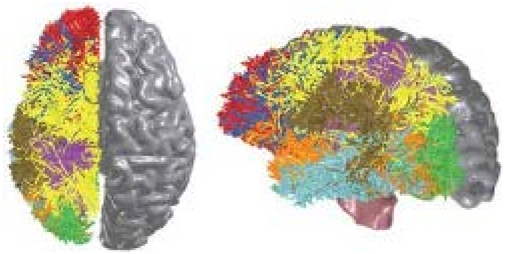


Models as Mirrors: Limitations



Necessary steps in designing Finite Element Analysis (FEA)

Models as Mirrors: Limitations

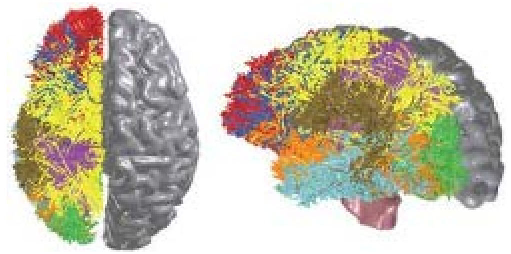


August 2, 2013

Although the simulated network is huge, it only represents 1% of the neuronal network in the brain…. The nerve cells were randomly connected…."

RIKEN News and Media

Models as Mirrors: Limitations



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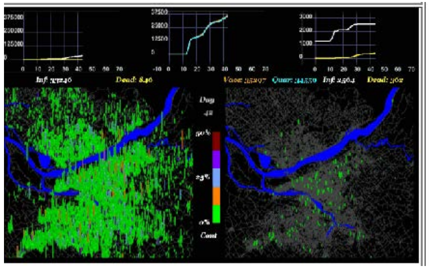

Assumption that the occupancy rate of locations within a city block are "nothing more than reasonable guesses"

Eubank et al 2004, supplement

Models as Mirrors: Limitations

Models as mirrors might function as ideal, but comes at a cost:

- lack of *simplicity*, *tractability*, *transparency*
- high *similarity to target*, *precision*

…. but not sufficient to avoid external validity issues

Module II: Models & Modelling

Video 7

Till Grüne-Yanoff

Kungl Tekniska Högskolan

Learning from models as Isolations

Isolating Models

Can a model be similar to its target and still be simple?

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Can a model be similar to its target and still be simple?

- Isolating models single out ***one*** aspect of the target, ignoring all the others
  - a causal factor
  - a property

Isolating Models

Can a model be similar to its target and still be simple?

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  - a causal factor
  - a property
- They represent the workings of ***that*** factor accurately

Isolating Models

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Arthur Cayley (1821-1895) – airplane consists of 3 separate systems:

Lift Propulsion Control

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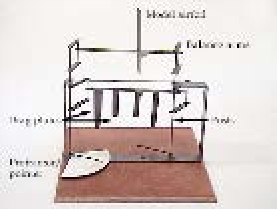
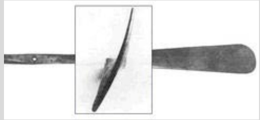
Lift



Propulsion

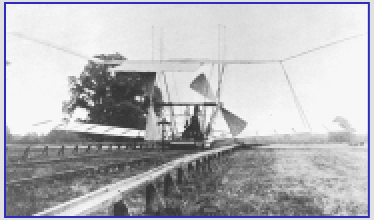


Control

Wright Brothers’ models for these three systems

Isolating Models

Different research strategies in early aeronautics



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Immediately construct flyable airplane

Isolating Models

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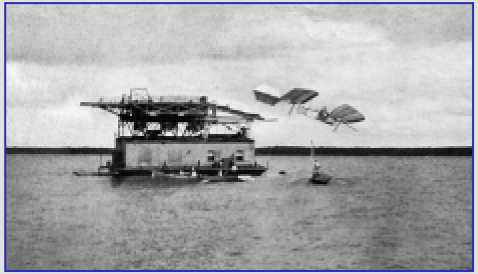

S. Langley (1896-1903)

Start with smaller scale model of flyable airplane

Isolating Models

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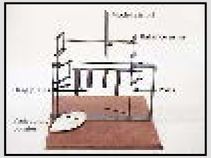

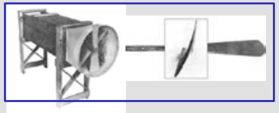

Wright Bro. (1896-1903)

Start with isolating models of components and then synthesise

Isolating Models: Limitations

- System must be dividable this way
  - Components must be truly independent
- Difficult to validate isolated models
  - Results of valid isolating models might not look like anything in the real world – because real-world phenomena are combinations of effects, while isolating model only represents one such effect
  - Validation either through synthesis – but that gives rise to a new version of Duhem-Quine problem; Or by carefully constructing isolating experiments