COMS30017
Computational Neuroscience

Week 3 / Video 1 / Modelling neurons

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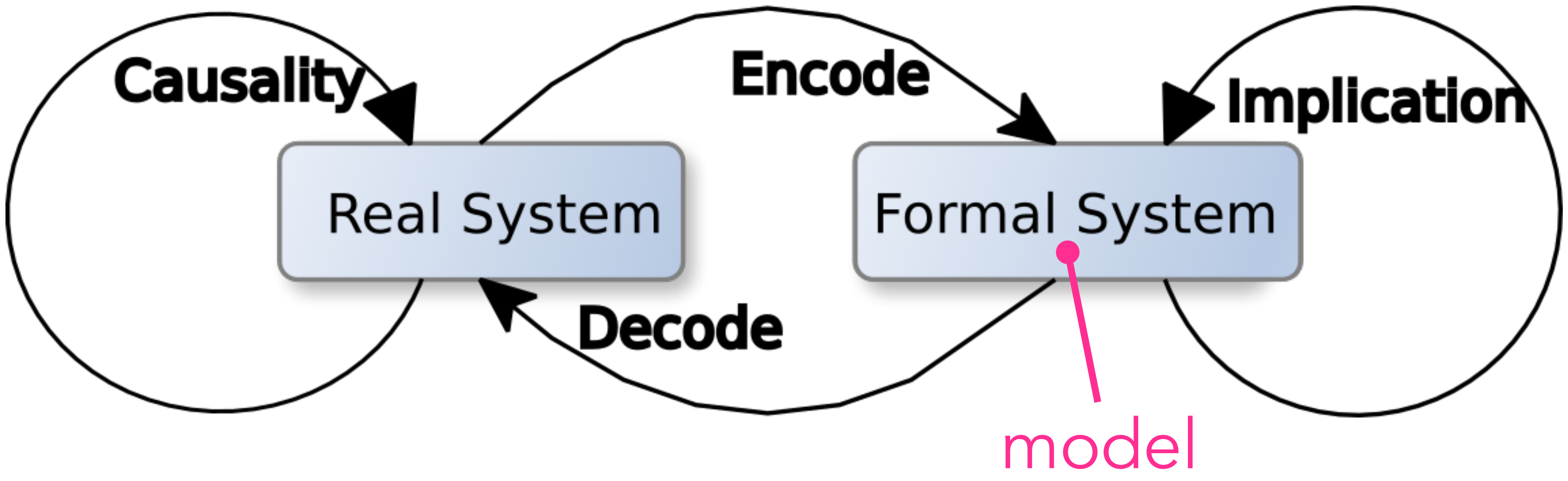
Intended learning outcomes

- Understand what a model is and why we use models.
- Appreciate the range of single neuron models used in computational neuroscience.
- Gain an intuition for how to choose the right model for a given problem.

What is a model?

- A model is a simplified version of a real-world system.
- Models can be:
  - Physical (e.g. scale models of buildings)
  - Analogical (e.g. billiard-ball model of a gas)
  - Phenomenological (e.g. integrate-and-fire neuron)
- Models can be represented by:
  - A physical object
  - Words
  - Mathematical equations
- Overview of the philosophy of models in science: https://plato.stanford.edu/entries/models-science/

What is a model?



https://commons.wikimedia.org/wiki/File:MathModel.svg

What is a computational model?

- Fundamentally, a computational model is just a mathematical model that is programmed and then solved or simulated using a computer.
- Technically speaking all computational models are phenomenological (for example, even in very detailed neuron models we ignore quantum mechanics).
- However in practice in neuroscience, most people consider phenomenological models to be those which abstract away all laws of (bio)physics.

What is the purpose of a computational model?

"All models are wrong, but some are useful."

— George Box

What is the purpose of a computational model?

To gain an understanding of a system beyond what we could achieve via word models alone.

Computational models can be used to:

1. "link levels", i.e. to ask if a mechanism at one level of description can account for a phenomenon at another level.
2. test if a set of concepts are mutually consistent. If not, why?
3. simulate experiments that are technically difficult or impossible to do in the lab.
4. validate a mathematical analysis that included approximations (…or errors).

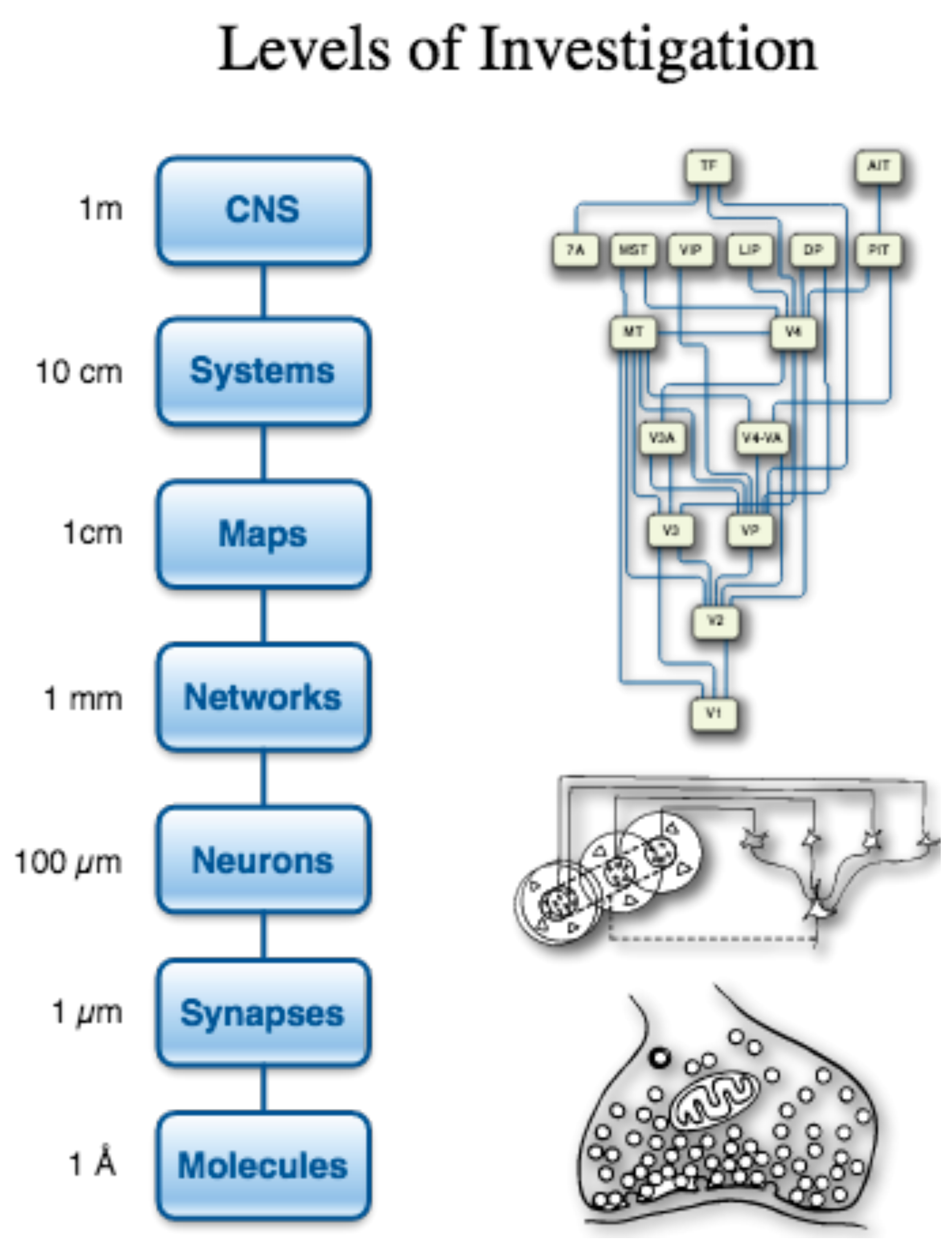
What is the purpose of a computational model?

Example usages of computational models in neuroscience:

- Hodgkin-Huxley model
  (to ask if the squid axon action potential can be explained by the voltage gating dynamics of sodium and potassium conductances).
- Simulation of recurrent hippocampal networks with synaptic plasticity
  (to ask if synaptic plasticity could mediate memory recall from partial cues).
- Simulating the biophysics of calcium signalling at a synapse (to explore what happens during synaptic stimulation).

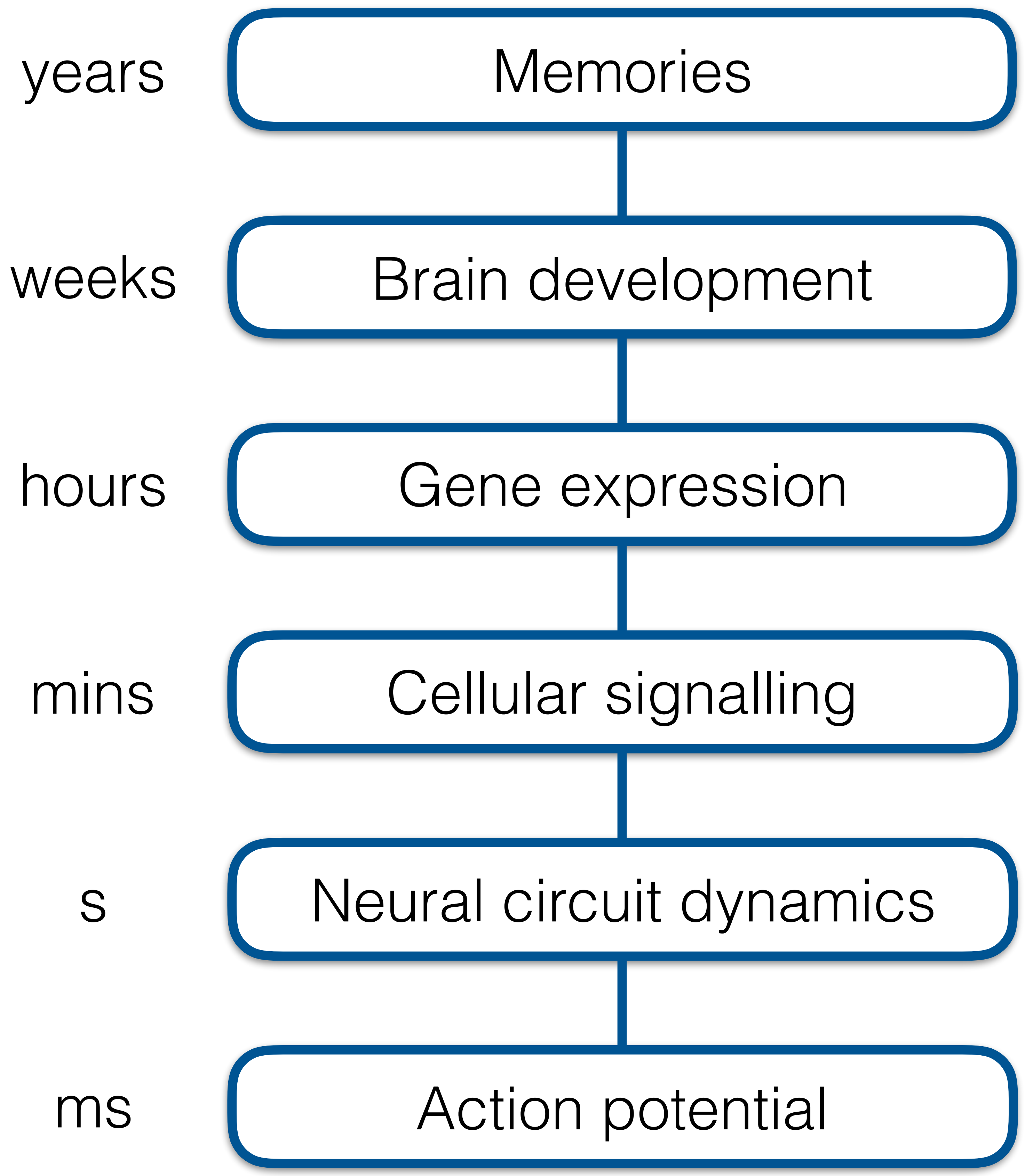
Scales in the brain at which a model could sit

Spatial

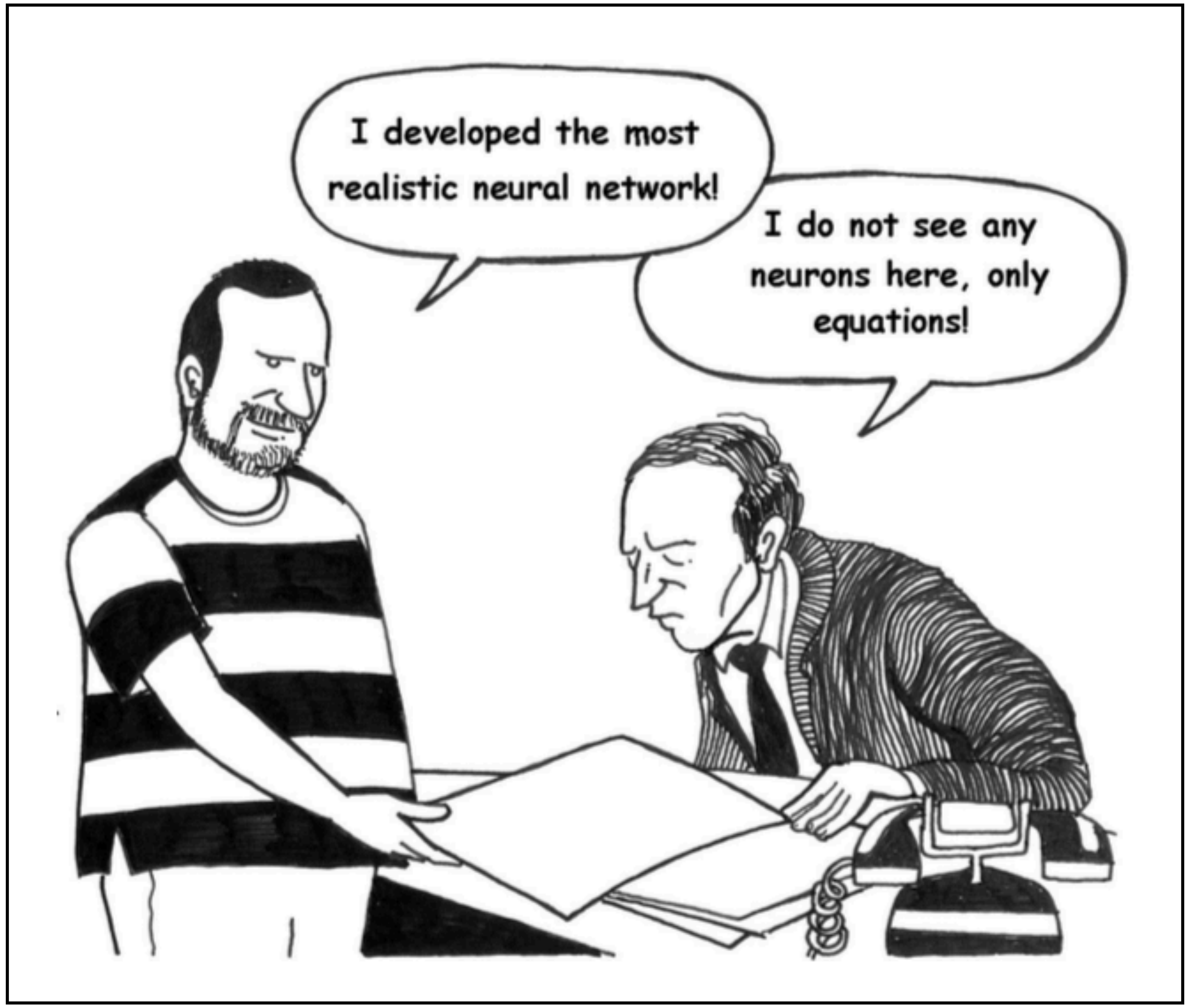


T. Sejnowski
http://cnl.salk.edu/

Temporal

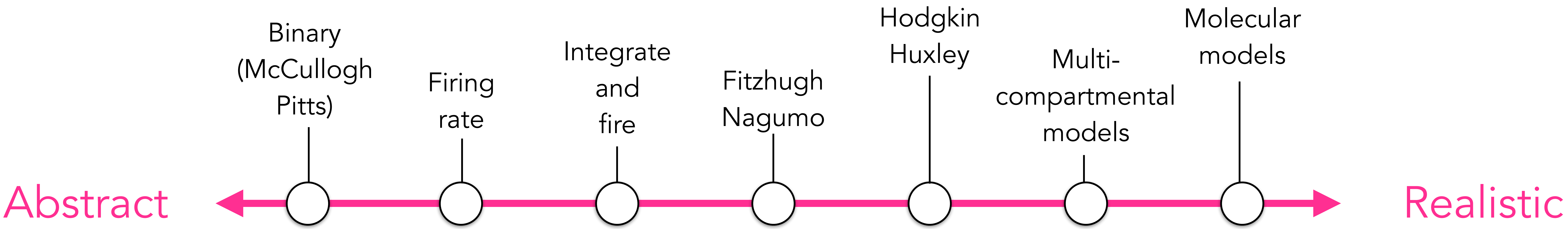


Models of single neurons



Dynamical Systems in Neuroscience: The Geometry of Excitability and Bursting.
Izhikevich E.M. (2007)

Models of single neurons



Abstract models		**Realistic models**
Simple	vs	Detailed
Hard to relate to biology	vs	Contains stuff you could measure
Few parameters	vs	Lots of parameters
Fast simulation	vs	Slow simulation
Mathematical analysis	vs	Intractable
Generic	vs	Specific

Which model is best for my problem?

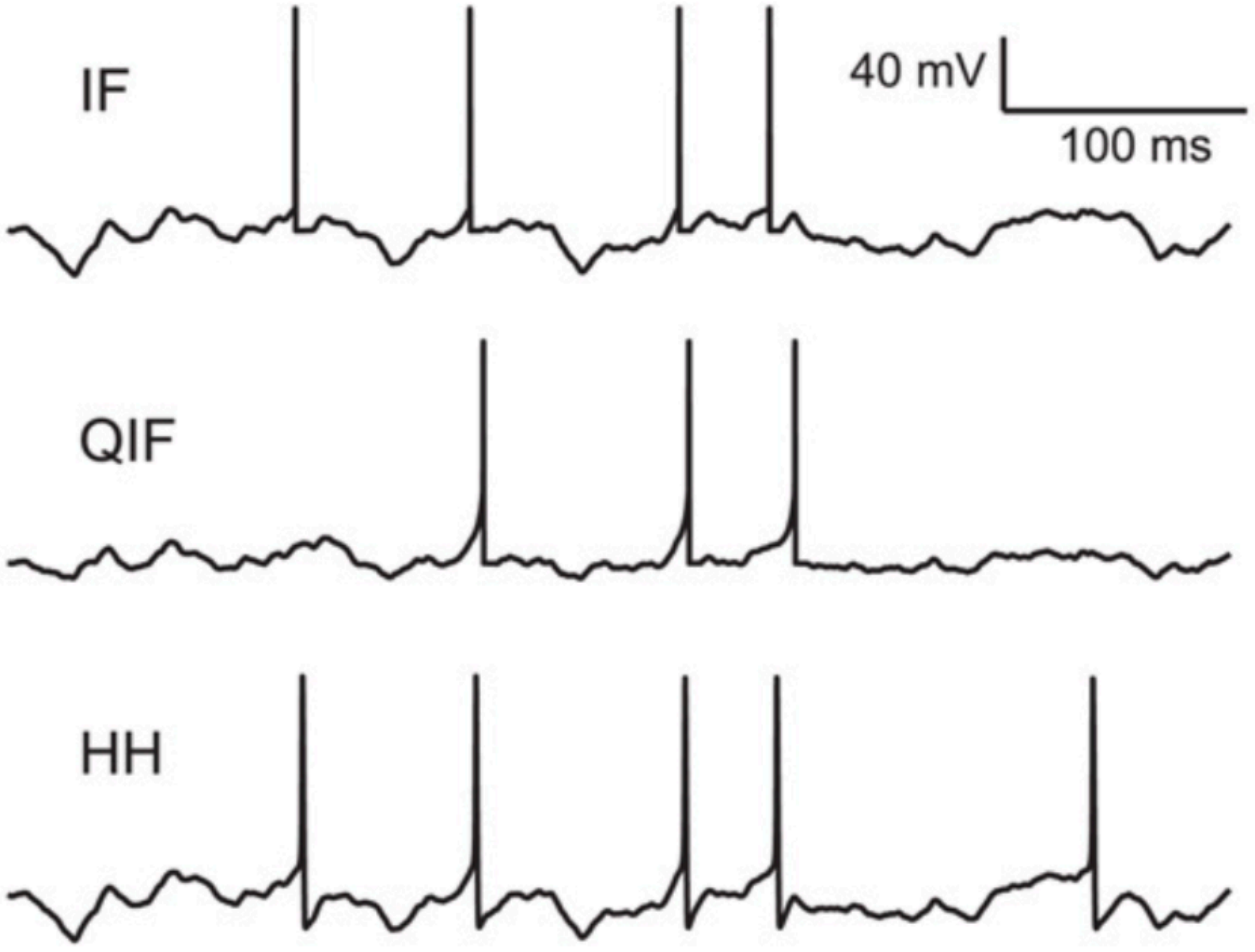
- Choose the form of the model that best matches the granularity of your scientific question.

- *"A model should be as simple as possible, but no simpler"*
  — Albert Einstein

- Often this choice is dictated by:
  - the data you have to constrain the model
  - the phenomenon you wish to explain
  - the computational resources you have available
  - how much maths/programming you know
  - ~~what someone else did previously~~

Details vs realism

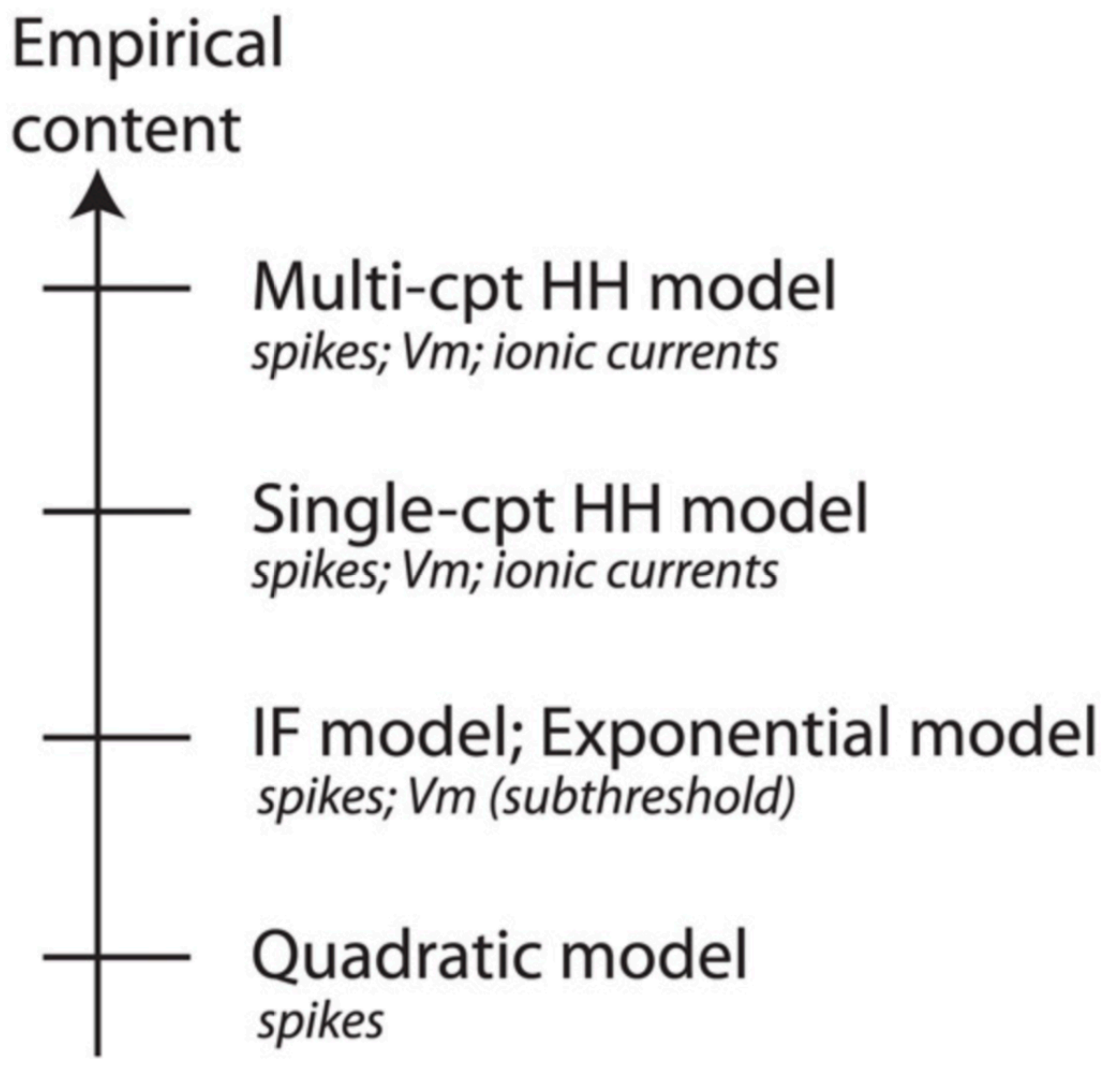
c.f. Brette, *PLoS Comput Biol*, 2015

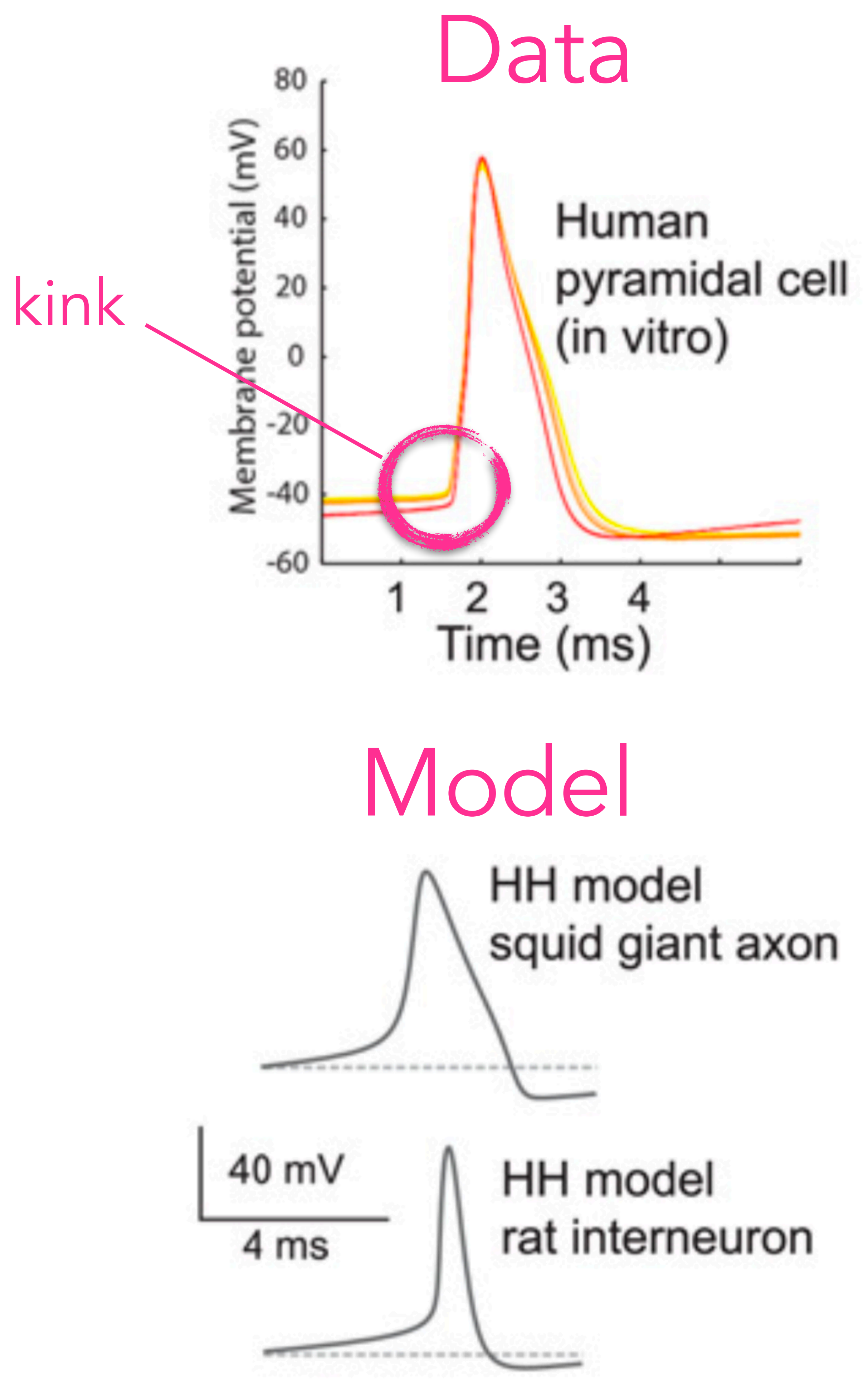


Voltage from three different model neurons in response to the same identical input current.

Brette, *PLoS Comput Biol*, 2015

Empirical content vs empirical accuracy





Brette, *PLoS Comput Biol*, 2015

Summary

- Models are simplified versions of real-world systems.

- In computational neuroscience models can sit at various spatial or temporal scales. But even at a single spatiotemporal scale, we can have models of different degrees of abstraction.

- Many single neuron model types are still used in computational neuroscience - the choice depends on the question.

- There is a distinction between empirical content in a model versus how realistically it captures the phenomena we hope to replicate.