Models

By Gunnar Blohm

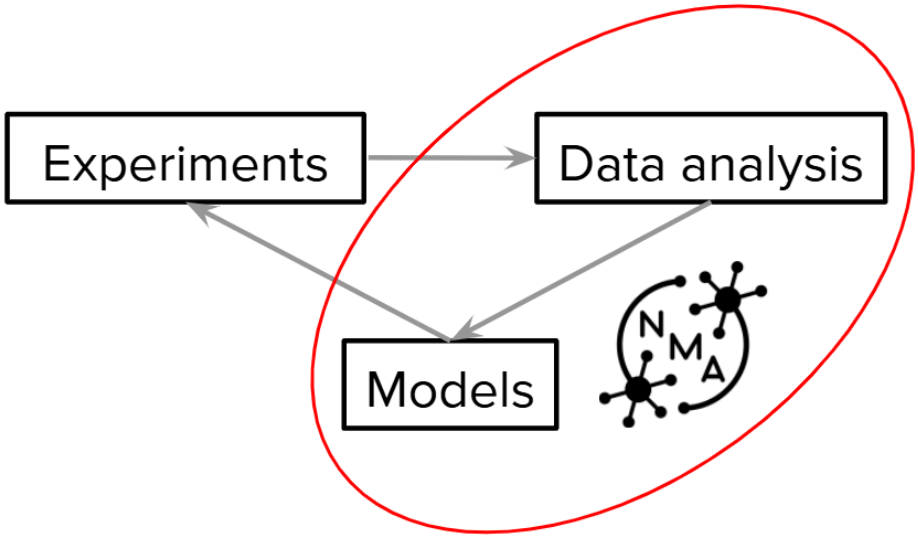
neuromatch
academy

Who is Gunnar?

- Co-founder & co-organizer of NMA
- Founder of CoSMo
- Prof @ Queen's U (Canada)
- Sensorimotor control

- A.k.a. The Viking
- Also big time into brewing beer...

Modeling and Data analysis



Why models are great?

- Knowledge synthesis
- Identifying hidden assumptions, hypotheses, unknowns
- Mechanistic insights
- Retrieve latent information
- A testbench for medical interventions
- Guidance in designing useful experiments ➔ quantitative predictions
- Inspire new technologies / applications

Why models are great?

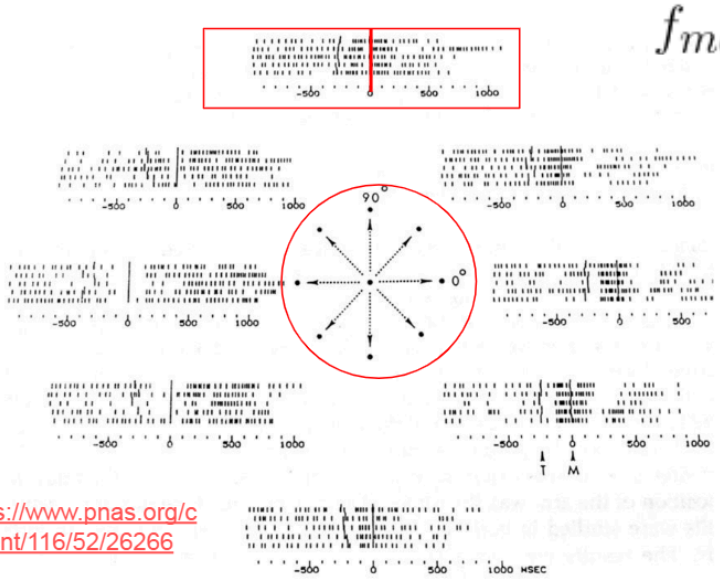
Let's consider 3 very different models:

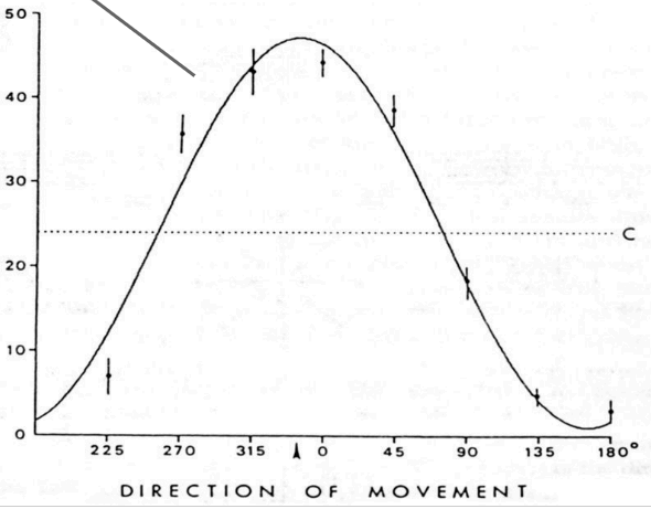
- Cosine tuning model of neuronal activity
- Hodgkin & Huxley single-neuron spike generation model
- Reinforcement learning model

What are the many reasons why they are helpful?

Cosine tuning (CT)

$$\frac{f(s) - f_0}{f_{max}} = \cos(s - s_p)$$





https://www.pnas.org/content/116/52/26266

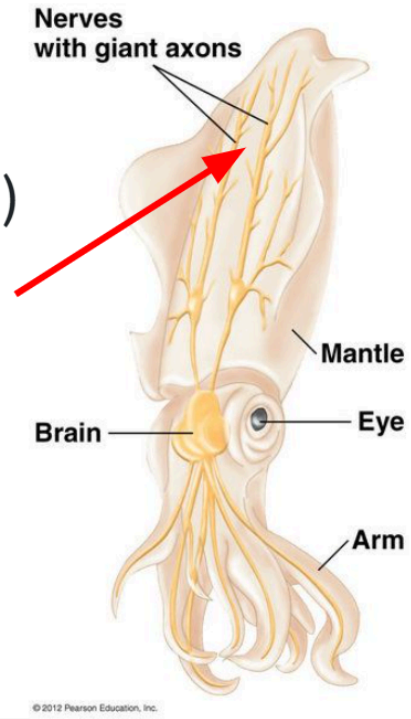
Why is CT helpful?

- It provides a really nice compact summary (**description**) of data
- It generalizes across movements
- It also applies for sensory stimuli
- We can use this for applications, e.g. brain-machine interfaces (prosthetics)

But...

- It's purely descriptive
- No consideration **how/why** cosine tuning arises
- Limited insight

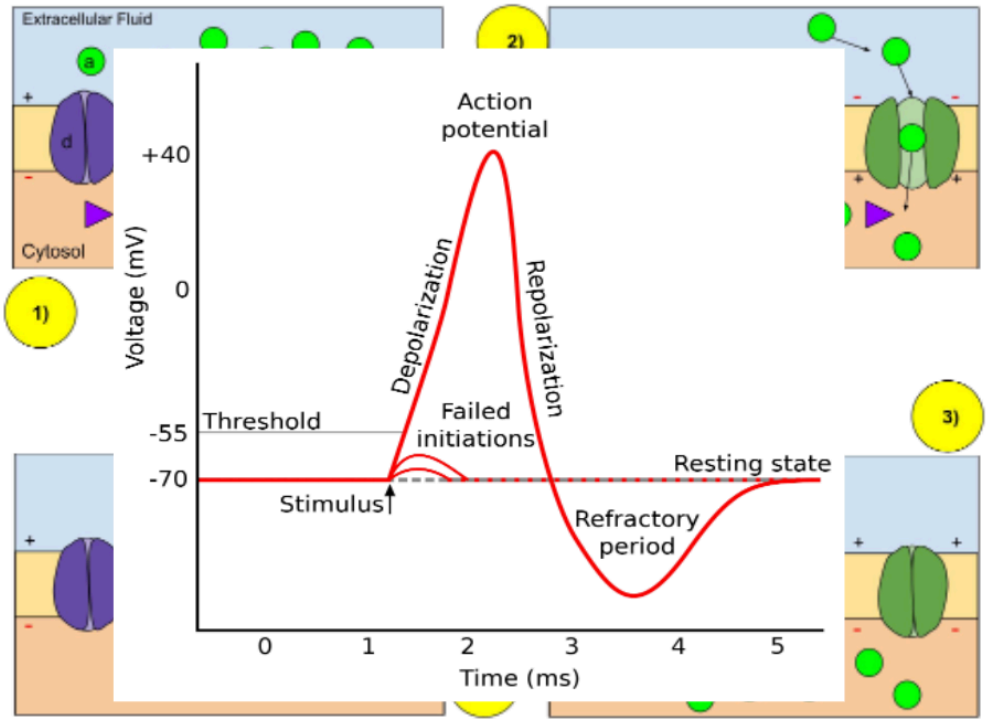
Hodgkin & Huxley (HH)



Longfin Inshore Squid (loligo pealeii)

https://www.scirp.org/journal/paperinformation.aspx?paperid=23595 (CC-BY)

Hodgkin & Huxley (HH)



a) Sodium (Na+) ion.
b) Potassium (K+) ion
c) Sodium channel.
d) Potassium channel.
e) Sodium-potassium pump

https://en.wikipedia.org/wiki/Action_potential

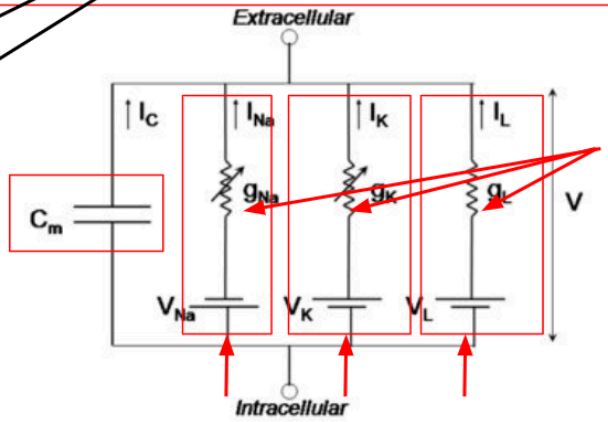
Hodgkin & Huxley

$$C \cdot \frac{dV}{dt} = -g_K n^4 \cdot (V - E_K) - g_{Na} m^3 h \cdot (V - E_{Na}) - g_L \cdot (V - E_L) + I(t)$$

$$\tau_n(V)\frac{dn}{dt} = -[n - n_0(t)]$$

$$\tau_m(V)\frac{dm}{dt} = -[m - m_0(t)]$$

$$\tau_h(V)\frac{dh}{dt} = -[h - h_0(t)]$$



http://www.scholarpedia.org/article/Conductance-based_models

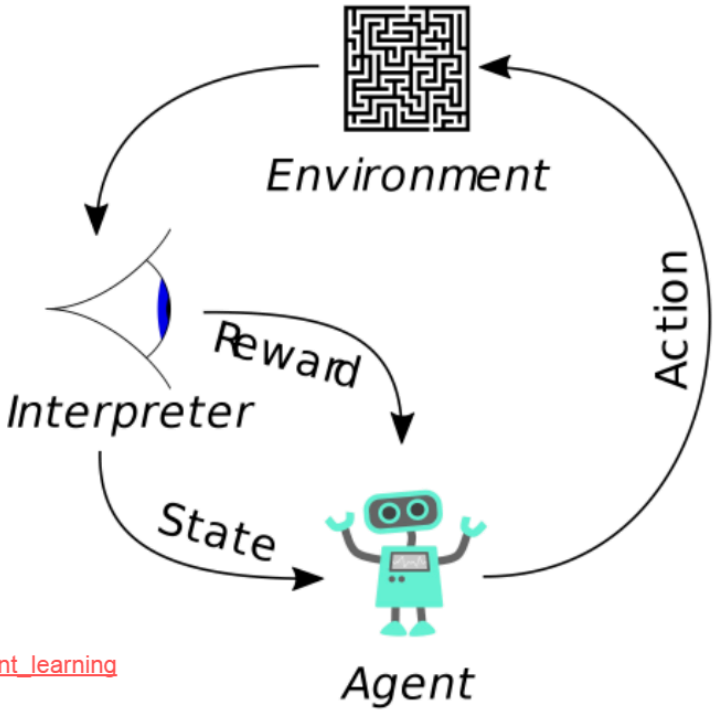
Why is HH helpful?

- Provides a **mechanism** for the generation of action potentials
- Synthesizes large amounts of neural data
- Describes variables that are not easily measurable (latent)
  - E.g. Channel opening/closing, currents for individual ions
- Allows for studying effect of interventions
  - E.g. How would a K channel blocker affect spiking?
- You can make real predictions
  - E.g. conditions controlling timing of action potential onset (threshold, refractory period)

But...

- No idea **why** ion channels open/close (molecular mechanism)

Reinforcement learning (RL)



https://en.wikipedia.org/wiki/Reinforcement_learning

Why is RL helpful?

- Provides a **normative** benchmark of what is best in theory
  - Including predictions for optimal behavior (under given assumptions)
- Allows to synthesize large amounts of behavioral and neural data
- Describes variables that are not easily measurable (latent)
  - E.g. reward prediction error
- Has inspired new technology
  - E.g. RL is central to modern AI

But...

- No idea about **how** the brain achieves this!

Why models are great?

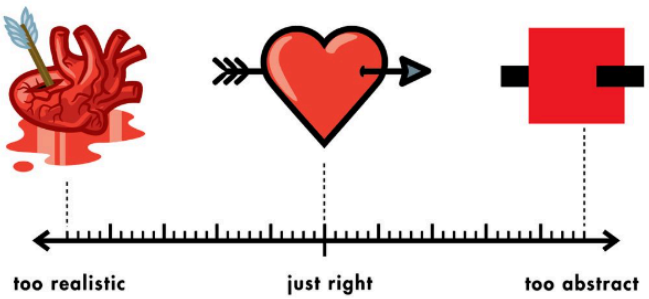
- Knowledge synthesis (CT, HH, RL)
- Identifying hidden assumptions, hypotheses, unknowns (HH)
- Mechanistic insights (HH)
- Retrieve latent information (HH, RL)
- A testbench for medical interventions (HH)
- Guidance in designing useful experiments ➔ quantitative predictions (HH, RL)
- Inspire new technologies / applications (CT, RL)

What are models?

Models are an abstraction of reality!

Models are partial, imperfect descriptions of the universe, developed by science for our understanding of the universe that is otherwise too complex to grasp by the limits of the human mind...

Rosenblueth & Wiener (1945)



https://computersciencewiki.org/index.php/Abstraction

What are models?

How do we find the right level of abstraction?

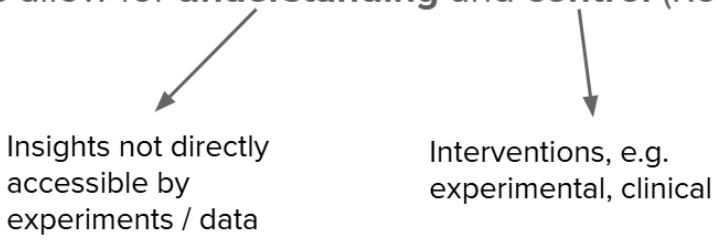
- Keep it as simple as possible, but as detailed as needed
- This is determined by our question, hypotheses and model goals! ➔ more during day 2

https://en.wikipedia.org/wiki/Occam%27s_razor

William Occam (1287 – 1347): “entities should not be multiplied without necessity.” - shave away unnecessary elements! (Occam’s razor)

What are models?

Models allow for **understanding** and **control** (Rosenblueth & Wiener, 1945)



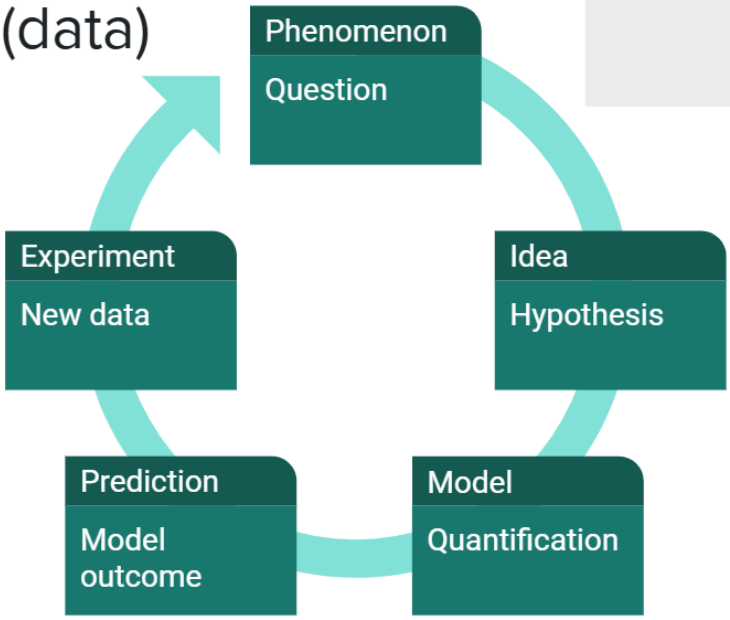
Requires model validation ➔ experiments!

In other words, a model is a **Hypothesis**!

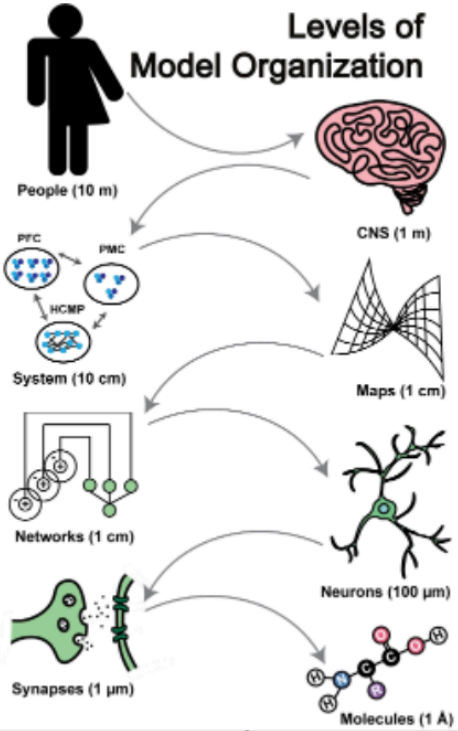
Models & experiments (data)

Cycle of discovery

- Models inspire experiments
- Data constrain models & provide new questions

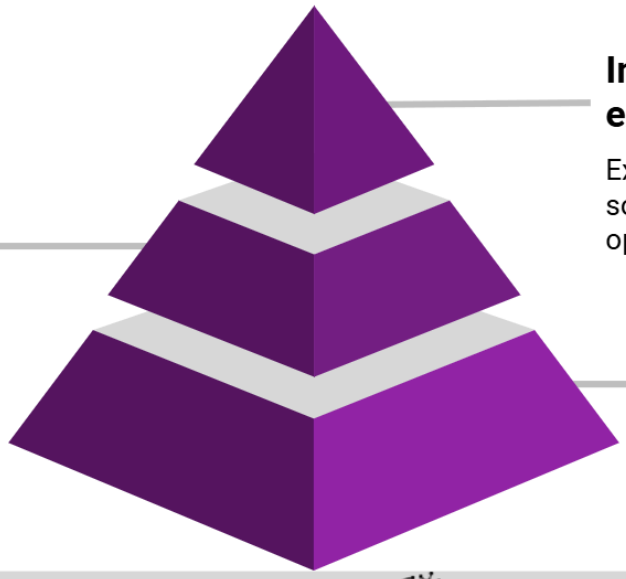


Models, Models, Models



Modified from Trappenberg (2009), *Fundamentals of Computational Neuroscience*

The model universe



Interpretive / explanatory - “why?”

Explain why the brain does something, e.g. because it’s optimal - **Tutorial 3**

Mechanistic - “how?”

Show how neural circuits perform complex function - **Tutorial 2**

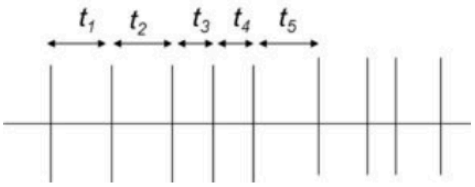
Descriptive - “what?”

Compact summary of large amounts of data - **Tutorial 1**

Dayan & Abbott (2001)

Exploring “what”/”how”/”why” in tutorials

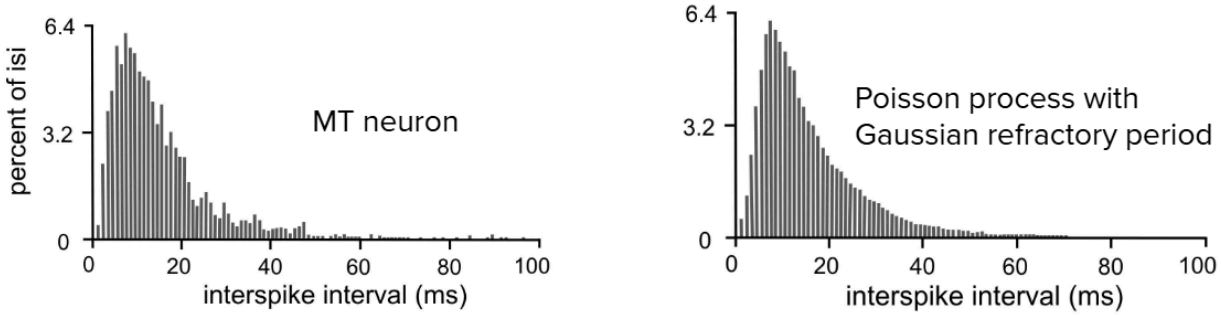
Examination of the interspike interval (ISI)



https://www.tau.ac.il/~tsirel/dump/Static/knowino.org/wiki/File_Spiketimes.html

- “What” is a good description?
- “How” is it generated in neurons?
- “Why” is this the best thing for neurons to do?

ISI description (“what”) - Tutorial 1



Modified from Dayan & Abbott, 2001

ISI mechanism (“how”) - Tutorial 2

What gives rise to the distribution of ISI?

Neurons in isolation can not do it...

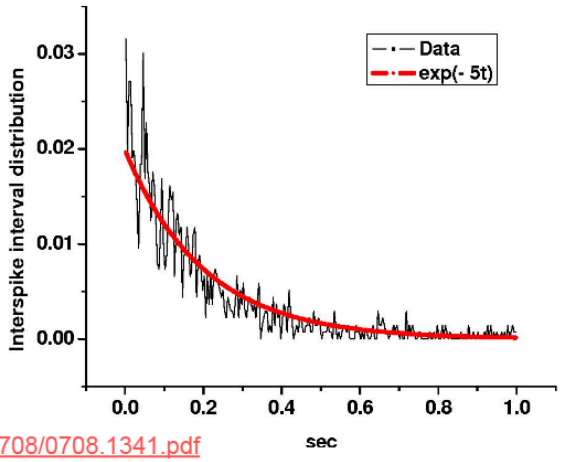
Excitation/Inhibition balance is important!

ISI explanation (“why”) - Tutorial 3

Let us assume that a neuron can not use more than a fixed number of spikes per hour (e.g. energy demands)

How could it use those spikes to transmit most information?

Have an exponential distribution of ISI!



https://arxiv.org/ftp/arxiv/papers/0708/0708.1341.pdf

Tutorial 4: model flavors

Group discussion

- Which model is best?
- Why do you think it's best?
- What's the most important thing in a model for you?

Enjoy!