Creativity on the Benchtop

What can we learn from student researchers on the frontiers of science?

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Creativity

- *act*
- *attribute/ability*
- *process*
- *problem-driven process*

cognitive-social-cultural nexus

Creative outcomes

- Ideas or artifacts that are *novel, surprising, and valuable* to some community
- 'Ideas' include concepts, poems, musical compositions, scientific theories, cooking recipes, choreography, jokes ...
- 'Artifacts' include paintings, sculpture, cartoons, steam-engines, vacuum cleaners, pottery, origami…
- *H-creative* vs *P-creative*

(adapted from M. Boden *The Creative Mind* 1990)

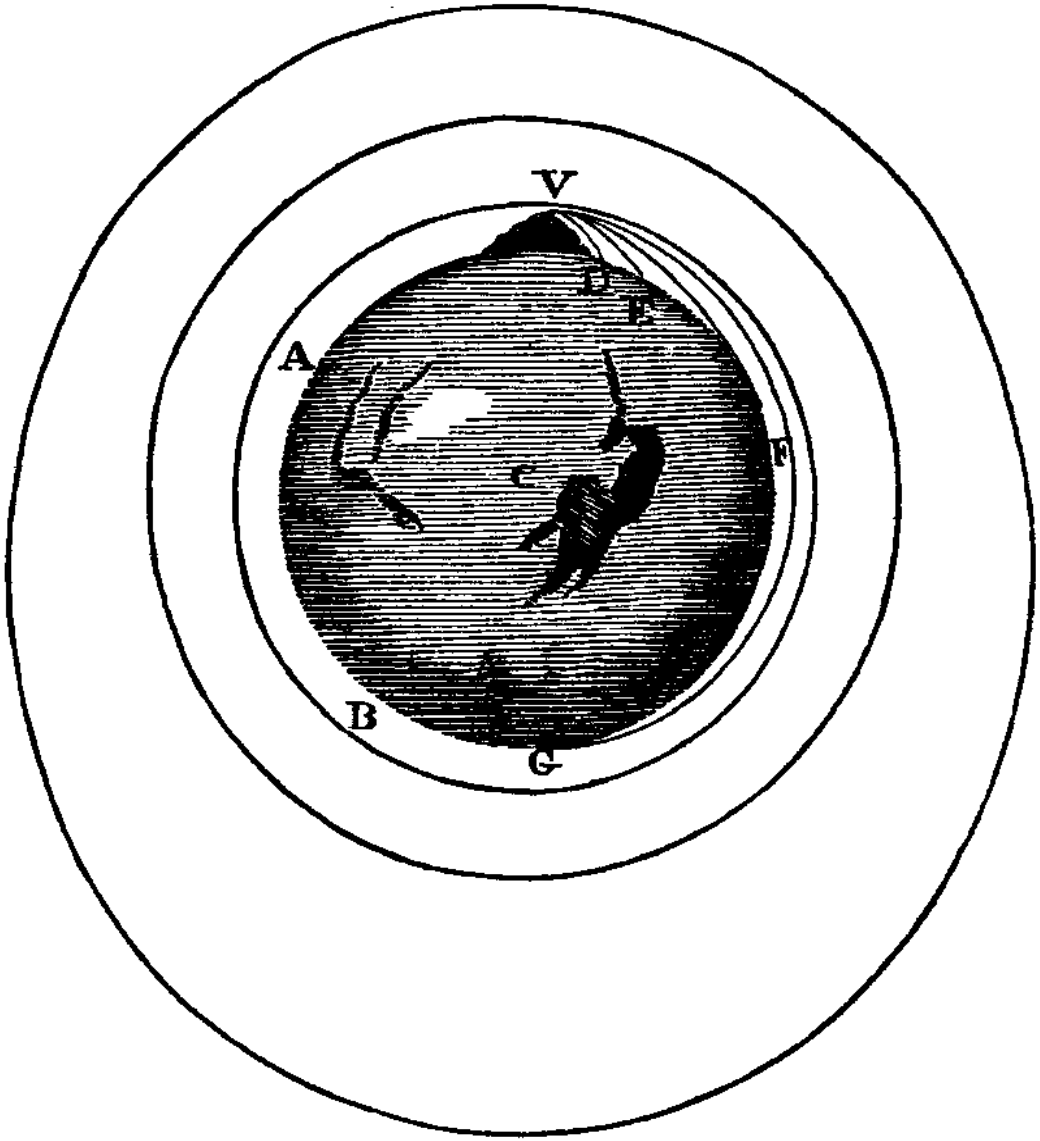
Scientific creativity

- Occurs within *complex dynamical systems* of scientist(s), artifacts, and problem-solving practices

  problem situations

- Involves the interplay among
  - specific problems
  - conceptual, material, analytical, resources
  - reasoning & representational processes
- Typically employs *model-based approach* to problem solving
  - integrated interpretation/representation of a phenomenon
  - analogy, visualization, thought experiment
  - conceptual, physical, computational

Creating Scientific Concepts (MIT 2008)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Interdisciplinary Research

"A mode of research by teams or individuals that ***integrates information, data, techniques, tools, perspectives, concepts and/or theories*** *from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or field of research practice.*

Facilitating Interdisciplinary Research, NRC (2005), 26

Varieties of Interdisciplinarity

Multidiscipline

Interdiscipline

Transdiscipline

Interdisciplinary research

Analysis of cognitive & learning practices in the context of pioneering research labs in the bioengineering sciences

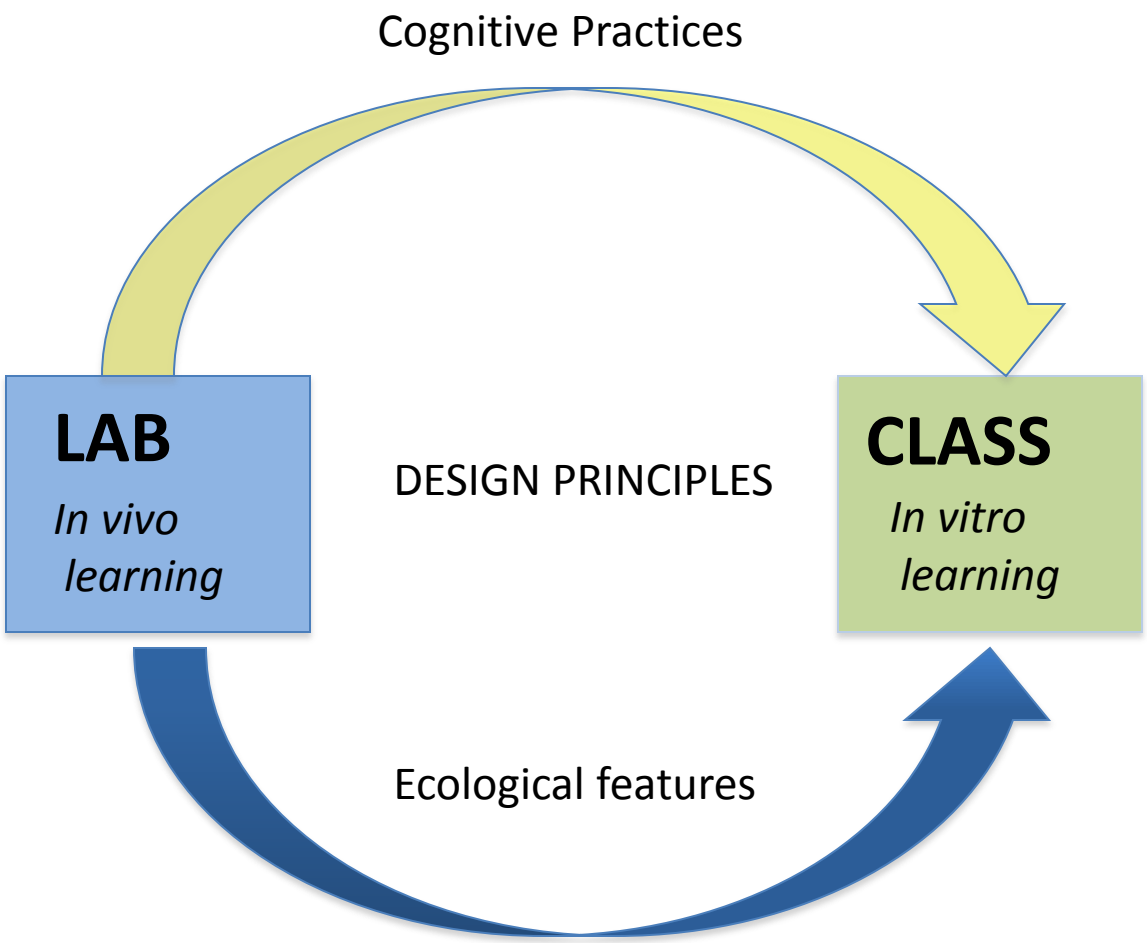
Tissue engineering

Neural engineering

Bio-robotics

Integrative systems biology (2)

TRANSLATIONAL STRATEGY



Characteristics to cultivate

- Cognitive flexibility
- Methodological adaptability
- Resilience in the face of impasses

Interdiscipline BME: neural engineering

***Guiding hypothesis*:** understanding the mechanisms of learning requires investigating the *network* properties of living neurons

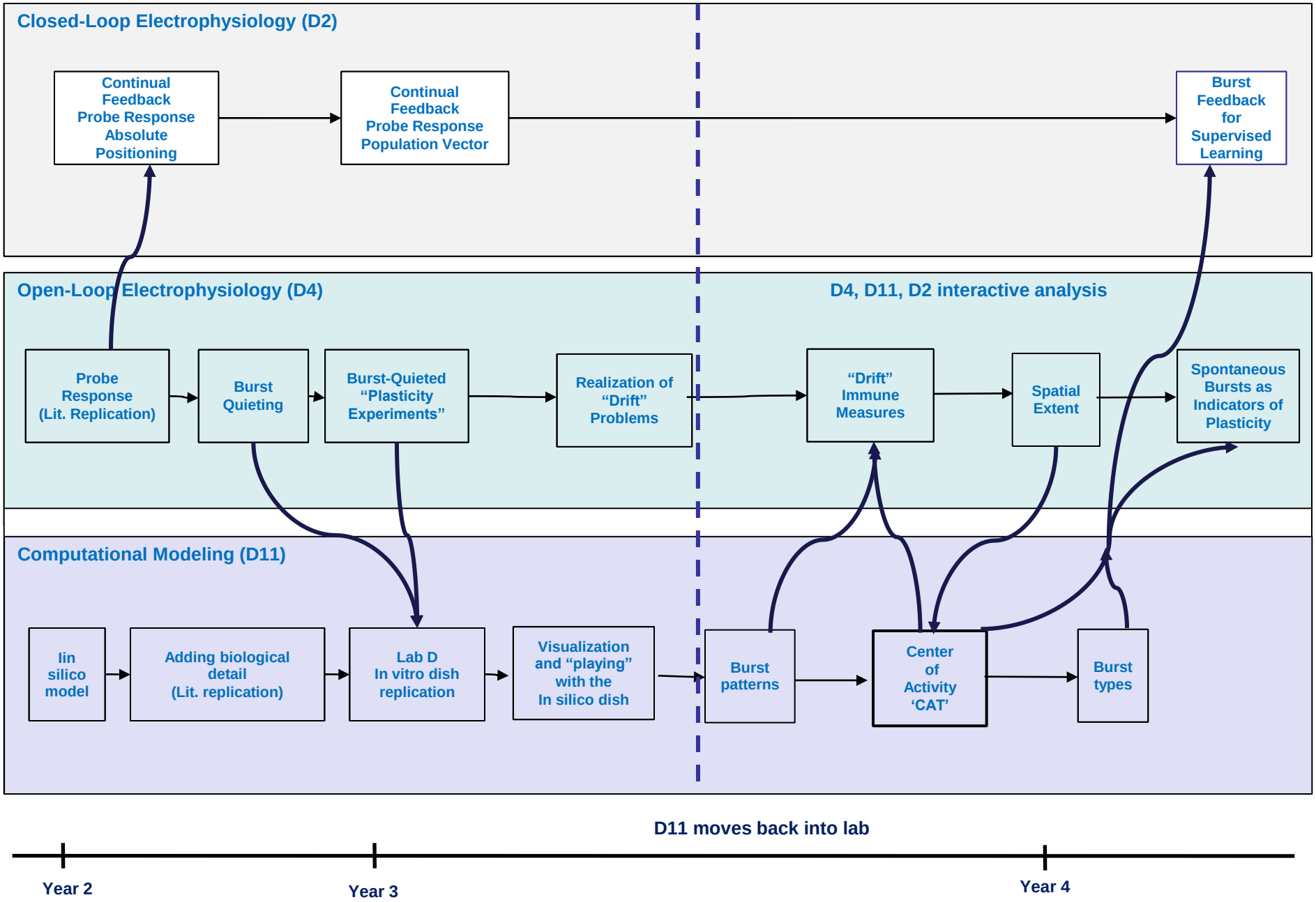
fundamentally new research paradigm

Overarching problem:

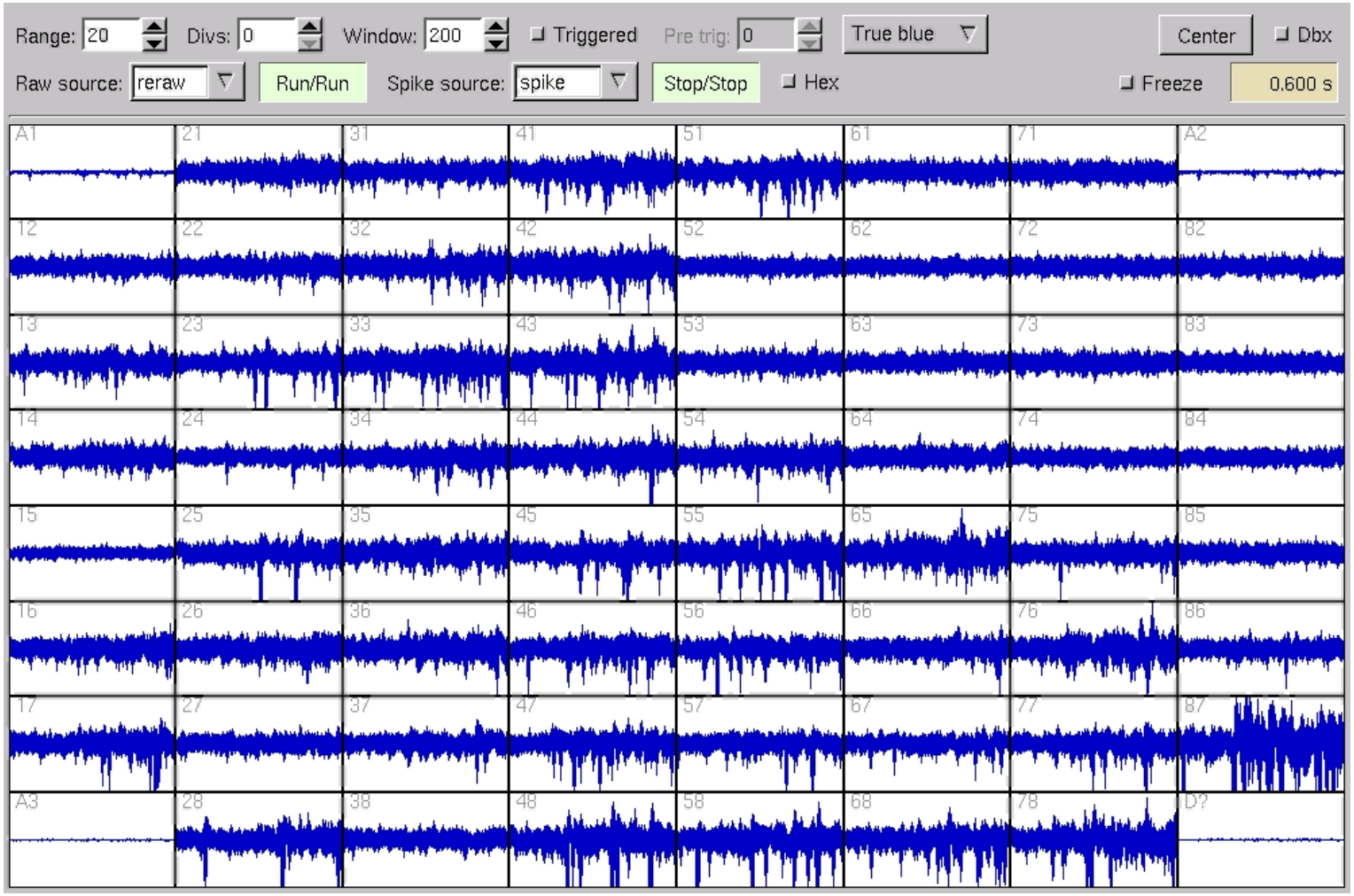
developing a control structure for goal-directed learning

Daily problems: developing neuron cultures; creating interfaces for stimulating and recording "the dish" of neurons; creating robotic embodiments through which "the dish" can learn; "quieting" the dish

part of the creative process


Closed-Loop Electrophysiology (D2)
Continual Feedback Probe Response Absolute Positioning
Continual Feedback Probe Response Population Vector
Burst Feedback for Supervised Learning
Open-Loop Electrophysiology (D4)
D4, D11, D2 interactive analysis
Probe Response (Lit. Replication)
Burst Quieting
Burst-Quieted "Plasticity Experiments"
Realization of "Drift" Problems
"Drift" Immune Measures
Spatial Extent
Spontaneous Bursts as Indicators of Plasticity
Computational Modeling (D11)
Iin silico model
Adding biological detail (Lit. replication)
Lab D In vitro dish replication
Visualization and "playing" with the In silico dish
Burst patterns
Center of Activity 'CAT'
Burst types
D11 moves back into lab
Year 2
Year 3
Year 4

Spontaneous Bursts dominate the activity patterns of networks in vitro



Electrophysiology Visualization via MEAbench

Concept of bursts as noise

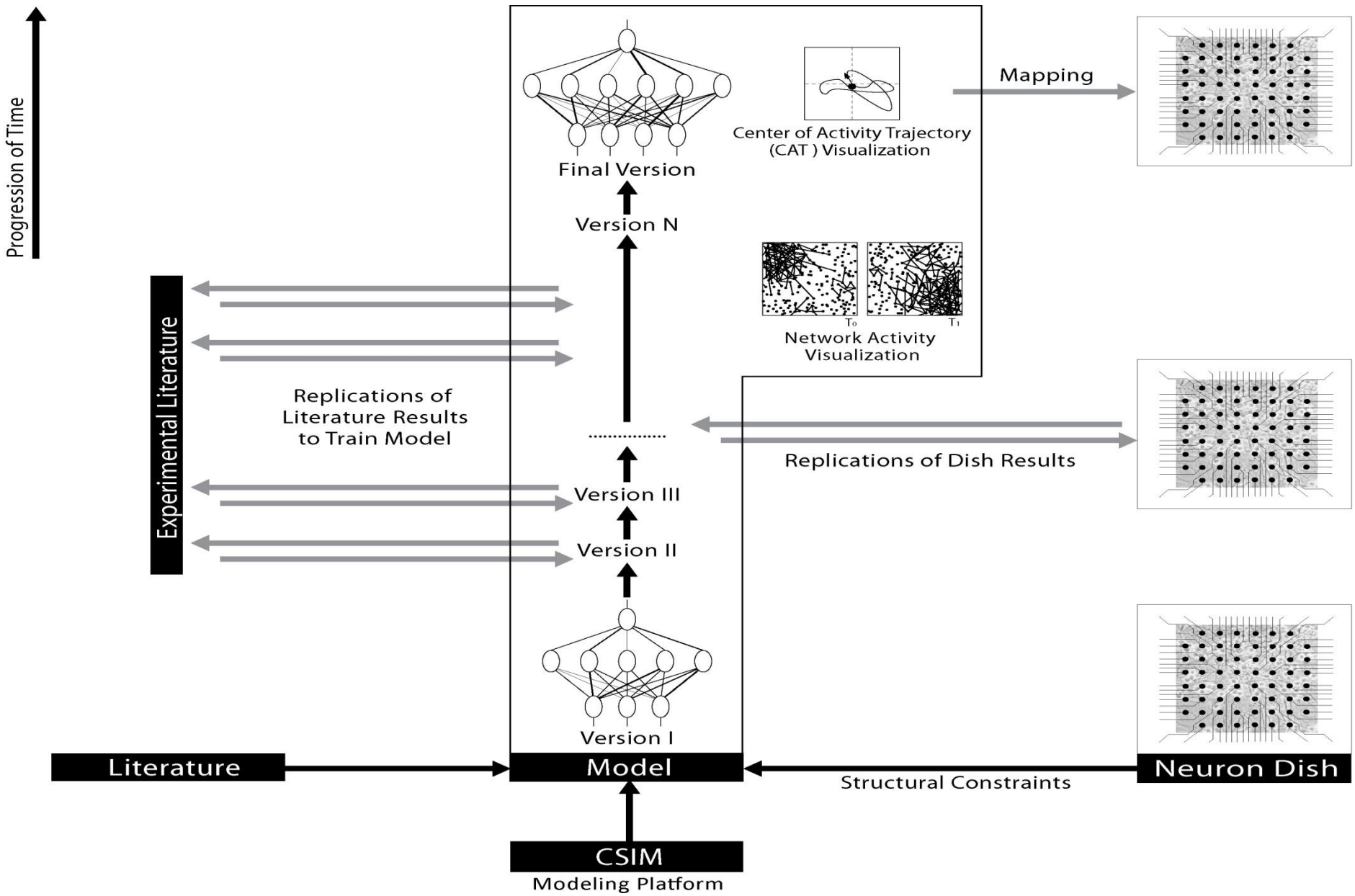
- Spontaneous network-wide electrical activity
- "Bursts are bad"

  "it is noise in the data – noise, interference – so it is clouding the effects of learning that we want to induce"
- Hypotheses
  - Learning requires burst-quieting
  - Quiet by providing substitute for natural sensory input: electrical stimulation

D11 – Computational Modeling

"The advantage of modeling [computational] is that you can measure everything, every detail of the network. I felt that modeling could give us some information about the problem we could not solve at the time" [quieting the dish, preventing drift]

Building the computational model



Computational modeling

- Processes of constructing the computational model facilitated
  - Building an understanding of the system in component terms
  - Building an understanding of how these interact dynamically to produce behavior

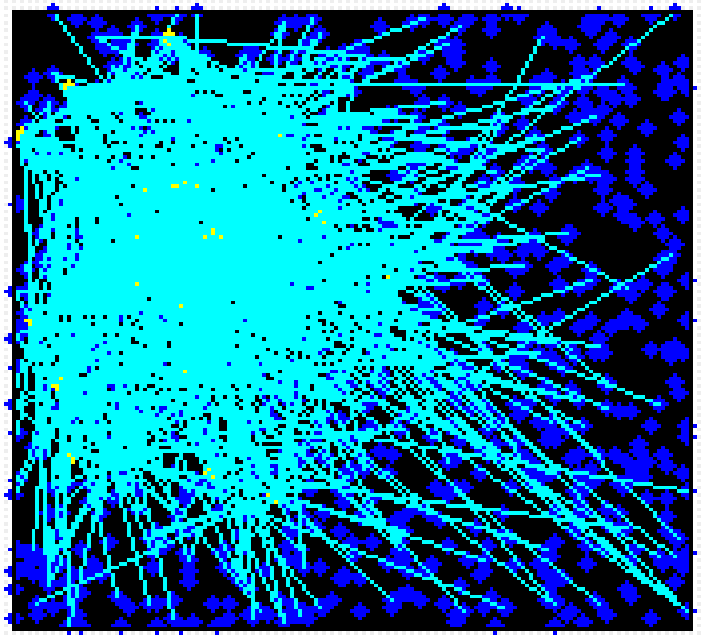
- Computational model afforded
  - Running unlimited scenarios
  - Stopping and restarting at any state – dynamically tracking variables
  - Visualization could enable “seeing in to the dish”

Computational visualization

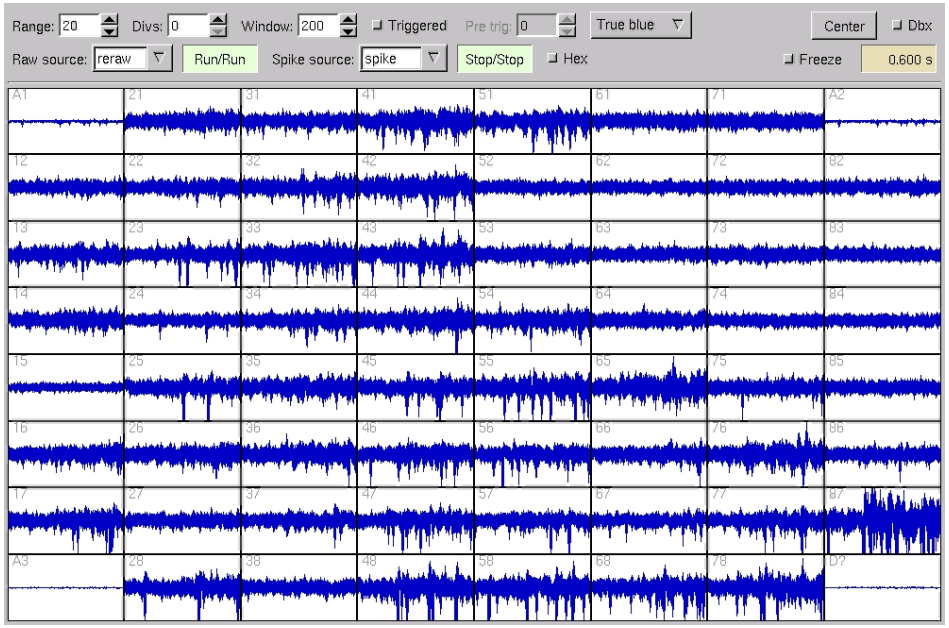
"I'm sort of a visual guy – I need to really look at the figure to see what's going on"

"I can visualize these 50,000 synapses and so you can see – after you deliver a certain stimulation – ***you can see those distributions of synaptic weight change – or synaptic state change"***

Network



Activity per channel

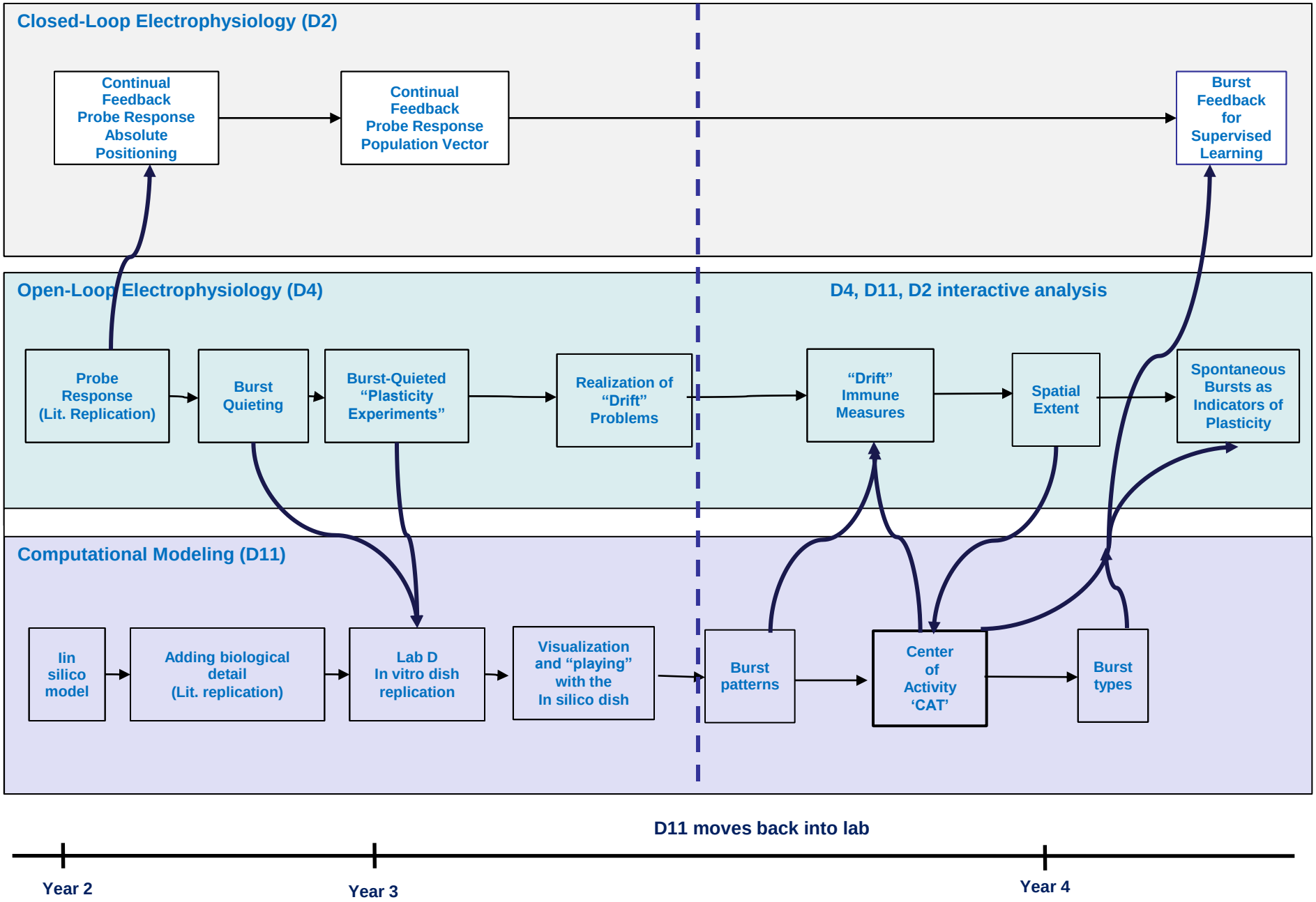


“seeing into the dish”

- Structurally similar looking bursts
- See small number of

“patterns of propagation”

“You get some feeling about what happens in the network and what I feel is that…. the spontaneous activity or ***spontaneous bursts are very stable****”*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Conceptual innovation: 'Center of Activity Trajectory' ('CAT')

"Bursts don't seem as evil as they once did"

Characteristics to cultivate

- Cognitive flexibility
- Methodological adaptability
- Resilience in the face of impasses

Designing learning environments

- Multiple socio-cultural support systems to cultivate resilience
- 3 Integrative core courses (2 faculty, different areas)
- Problem-based learning course

  Problem 1: Experimental design

  Problem 2: Mathematical & Computational modeling

  Problem 3: Mapping your lab's research space

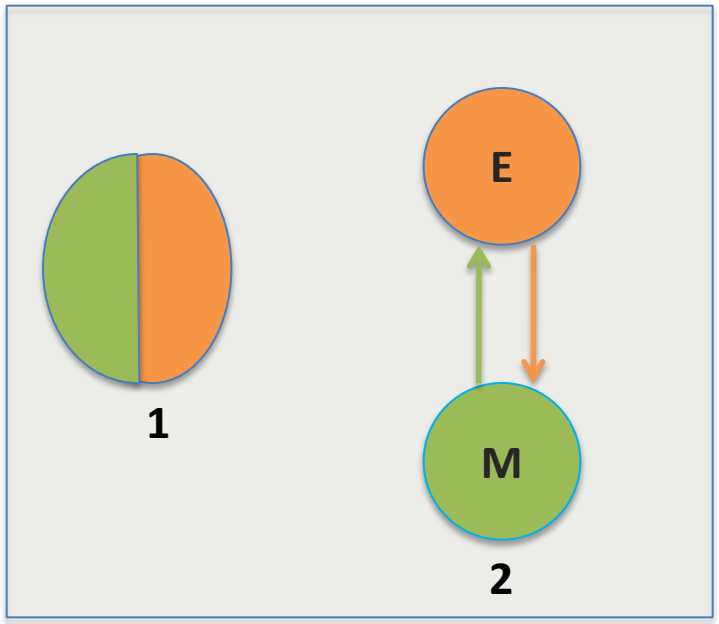
Characteristics to cultivate

- Awareness of epistemic values
- Interactive expertise

IE: Collins, H.M. and Evans, R.J. (2002) 'The Third Wave of Science Studies: Studies of Expertise and Experience', *Social Studies of Sciences*, 32: 235–296

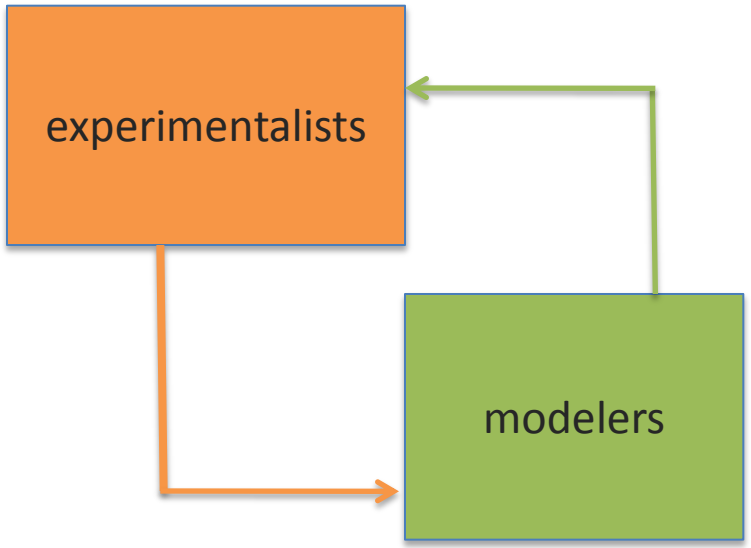
Transdiscipline: ISB practice models reflecting a "philosophical divide"

Bi-modal model



Bimodality can manifest either in one researcher (1) or within lab collaborations(2)

Uni-modal model



Uni-modality manifests as two separate research partners undertaking complimentary but different activities

"Philosophical divide"

- Lab G director: uni-modal lab best

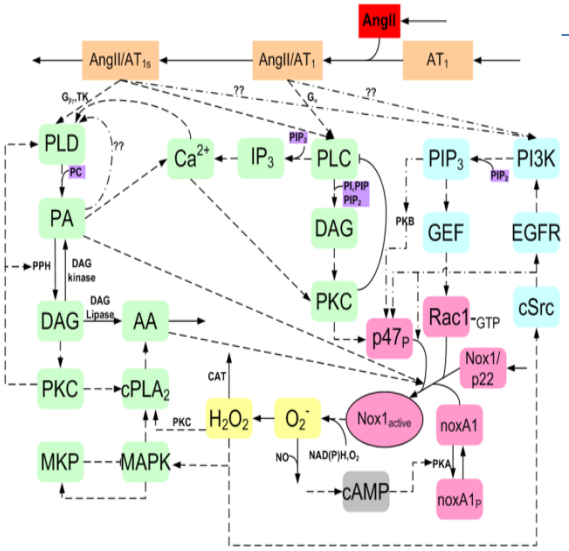
  "you need 10 experimentalists for every modeler"

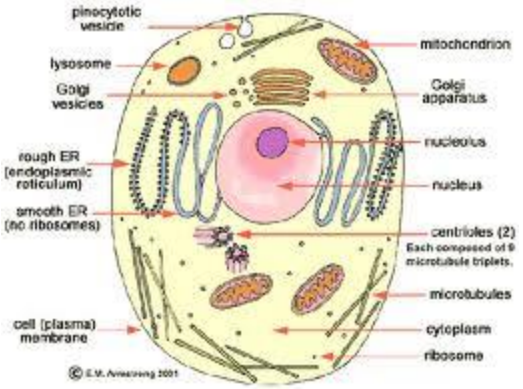
  "problem of diluting both sides… modeling lite and experimenting lite."

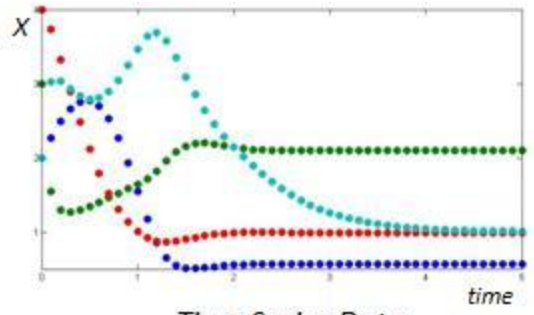
- Lab C director: bi-modal lab best

  "I tell my students never do this [sequential]. You should always do these things in parallel… I ran into the learning curve issue that early graduate students face – only here I was 4.5 years in and starting from scratch on some of these things."

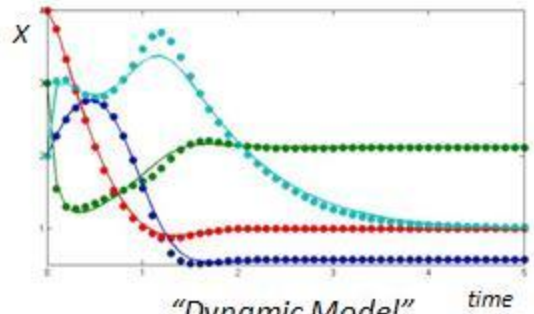
Building the simulation model







Time Series Data



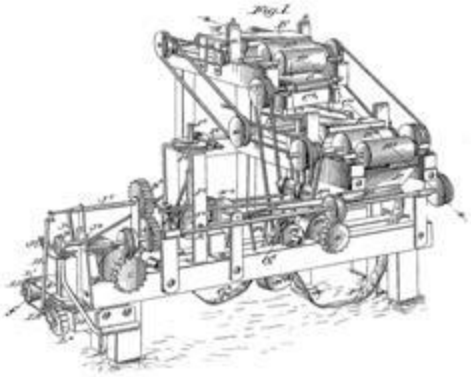
"Dynamic Model"

Unable to produce acceptable fits

Model of Choice

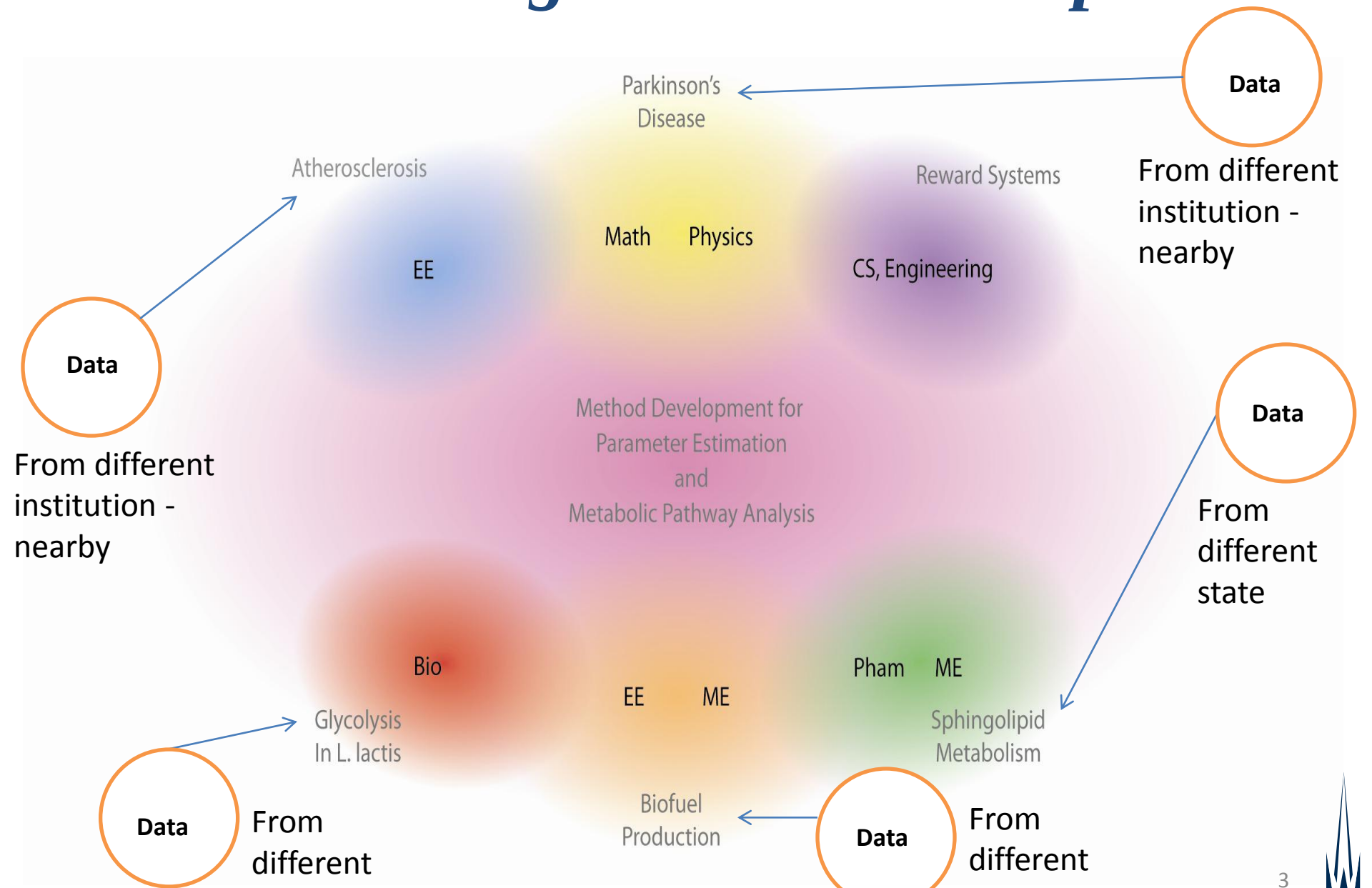
$$\frac{dX_i}{dt} = \dot{X}_i = \sum_{p=1}^{P}\left(\pm\gamma_{ip}\prod_{j=1}^{n}X_j^{f_{ipj}}\right), \quad i = 1,2,\ldots,n$$

"Symbolic Model"



Parameter Estimation

ISB Modeling Lab: research space



G10:Finding a remedy for "recalcitrance"

- Problem: to model the lignin pathway of alfalfa to determine if it is possible to break down it's "recalcitrance" and produce a biofuel

- Collaboration with a biofuels research lab which is to provide the experimental data for building and validating the model

G10:Finding a remedy for "recalcitrance"

- Collaboration with a biofuel research lab

"the biologists produce the data they want, but these are not the data we want when we do parameter estimation"

"sometimes you want to ask him question, and he would get back to you in a month – or even 2 month – or even don't reply"

"right now they have give us the data they have published, but we want more data… not yet published"

Changing the lignin pathway

"So based on our analyses we add these three arrows… we need these 3 reactions to be reversible so that our data can be explained by the model. So these blue arrows are actually our … new findings… We suggest there – this original pathway needs to be modified so that this data can be explained."

Discovering "X" effecting the lignin pathway

"So this is actually the biggest finding from our model. So by adding this reaction you can see that we hypothesize that there is another compound that can give … a feed forward regulation to other parts of the pathway…I guess our findings will give them more confidence in what we are doing so maybe in the future they could be more willing to… share more data."

Positioning of biologists by modelers

- **Recipe followers**
  - *"biology is memory"*
  - *"in their daily experiments…they will follow those instructions, that's their way to do things"*
  - *"it's [assay learning] not that difficult – like a recipe – when you cook"*
- **Mathematically inept**
  - *"if you let a medical student to learn this structure or the algorithm, wow, they will fail, trust me only 1%-5% can survive"*
  - *"it's too difficult for them to learn these things… the philosophy of biology and mathematics are … totally different"*
- **Model is "black box"**
  - *"they treat it as a black box… they will not get deep into the model's detail because that's maybe too complicated"*
  - *"it doesn't make any sense to them"*
  - *"they don't care time series… how this dynamically changed. They just care what is the result"*

Positioning of modelers by biologists

- **Experimentally naïve**
  - *"sometimes they ask things that are not biologically possible"*
  - *"the data they want is not that simple to generate"*
  - *"time consuming and money and effort or sometimes we already passed that point"*
  - *"they don't know how to ask the right question"*
- **Not caring about "accuracy"**
  - *"they are not really interested in actual numbers… more like getting sense rather than .. accurate"*
  - *"we know how complicated the system is… one change in experimental condition can totally change the result"*
- **Modeling for modeling's sake**
  - *"trying to model something published 15 years ago… well what are you going to do with that?"*
  - *"not taking it to the step where it's useful for the biologist… more interested in making a system to describe the system"*

Characteristics to cultivate

- Awareness of epistemic values
- Interactive expertise

IE: Collins, H.M. and Evans, R.J. (2002) 'The Third Wave of Science Studies: Studies of Expertise and Experience', *Social Studies of Sciences*, 32: 235–296

Small interventions – big payoffs

Experimental "summer camp" for modelers

"Some of the stuff I saw I actually, like, pipetted a little bit. So I got a little bit more self confident… So, sometimes, like in a month, you just like change inside. It's not about the exact things you learn…That you know what to learn… it's just knowing how to learn stuff."

"Now I feel more self-confident in talking to biologists"

"If I need to order experiments…which experiments are more expensive to do or which… are lot more labor"

"Right now I would say there's a lot of human error in there… it's both about the reliability of the data and the types of errors"

Small interventions – big payoffs

Introductory bio-systems modeling course for biologists &modelers

"I wish I had taken this class 2 years ago. I wish [modeler] and I had…taken it together. We would have looked at each other and said 'Oh, I get it – I know what you are doing now.' It would have been very helpful for me to understand what kind of data he needed; to understand what kinds of questions he should have been asking of me."

"I wasn't sure how he converted what I gave him into code… I am now going 'Oh, that's what he wanted; that's what he needed. Oh, OK, I wish I had known that.'"

"It's like my whole training was 'Don't make assumptions.' If you are modeling you have to start by making an assumption…assume this system is going to behave similar to this."

- As graduate educators we are responsible for enhancing the potential of our students to advance the frontiers of knowledge
- This requires that we attend to creating environments that support and nurture characteristics that promote creativity
  - cognitive flexibility
  - methodological adaptability
  - resilience in the face of impasses
  - awareness of epistemic values
  - interactive expertise
- This effort can benefit from collaboration with cognitive and learning scientists