The Temporal Dynamics of Learning Center (TDLC): Better Learning by Advancing the Science of Time

Garrison W. Cottrell, PI
At each point in **TIME**, the brain changes to best meet the changing demands of the environment.
Time: The missing link between brain and behavior

• Understanding how the brain learns is important for understanding how students learn in the classroom.

• And how the brain learns depends crucially on time and timing.

• Here, I will develop one example that is a model for what we hope will be replicated many times by our Center.
Time matters for processing...

These wave forms are **identical** except for the artificially inserted gap! Yet we all hear a /t/ inserted...
Time matters for learning...

This baby has learned that exciting things go on to her left when the two tones are different -- at a 70ms “boop-beep” interval...
Time matters for learning...

6-8 year old children with a language impairment can’t do this task at short delays: *correlation or causation?*
Time matters for learning...

Looks like *causation*:

- Rapid auditory processing (RAP) ability at 6 months of age accurately predicts language impairment (with 91% accuracy) at 3 years of age.

- Remarkably, *training* children to make these distinctions with the FastForWord program can improve reading.

- This training is grounded in basic research on neural plasticity from animal models.

Benasich & Tallal (2002) *Behav Brain Res.*
Time matters for Education...

This child is trying to detect whether two tones are both rising, rising and falling, or both falling (FastForWord).
Time matters for Education...

After considerable training, the child is able to perform the task at a much faster rate.
Compared to non-treatment controls, such language-oriented training leads to **improved reading**.

Temple et al. (2003) PNAS
Brain activity differs between controls and dyslexics: 
Training alters functional activity such that it more closely resembles normal activity

Temple et al. (2003) PNAS
Time matters for learning: at this short time scale...

- Abnormalities in *temporal processing* at the 20-50 ms time scale lead to poor phonemic perception...
- Which leads to a *cascade of detrimental learning effects* on ALL longer time scales: Poor language skills.
- By concentrating on *remediating* the basic temporal processing deficit, we can improve higher-level performance.

Temporal perceptual weakness

↓

Weak phonological representations

↓

Oral language weakness

↓

Reading, writing, spelling problems

↓

Learning and academic problems

↓

Struggling students
And at *Many* Time Scales

- **5-20 ms** – Synaptic integration, spike-timing dependent plasticity (STDP), speech
- **50-200 ms** – Event and motor sequence perception/production
- **200-500 ms** – Fixation duration, attentional blinks, saccades, attention shifts, timing of social interactions
- **0.5-2 s** – Perception, motor rhythms, emotional expressions
- **2-50 s** – repeated exposure and training effects, reward signals
- **minutes, hours, days, months, years**: Spacing effects, memory consolidation, analytic/holistic changes in expertise
Our Challenge

- Develop a new **Science of Learning Dynamics** that treats **time** as a crucial element of the process.

- Integrate the study of the **dynamics** of learning across multiple time scales, brain systems, individuals, and social systems.

- Change educational **practice** based on sound science.
Meeting This Challenge Requires:

- Well-organized collaborations between scientists from multiple disciplines.
- Large-scale data infrastructure that makes data persistent and accessible to many scientists.
- Theoretical models capable of spanning time scales.
Seems like a tall order....

How will we do it?

A new kind of Center:

The *Network-of-Networks* research structure
The Network-of-Networks Solution

UC San Diego
Rutgers University
Vanderbilt University
UC Berkeley
University of Colorado
The Salk Institute
Queensland University
Victoria University
Brown University
Carnegie-Melon University
Yale University
San Diego State University

SensoriMotor Network
Social Interaction Network
Interacting Memory Systems
Perceptual Expertise Network

Mathematics
Physics
Machine Learning
Robotics
Computer Science
Computational Neuroscience
Neuroscience
Cognitive Science
Linguistics
Neuropsychology
Cognitive Psychology
Developmental Psychology
Learning Theory
Education

Temporal Dynamics of Learning

The Vision
Why these four?

Sensorimotor Learning mediates our interactions with the world

Interacting Memory Systems maintain continuity across time

Social Interaction provides the context for this learning - especially in the classroom

Perceptual Expertise allows us to fluently and appropriately interact with the world
A proof of concept:
The Perceptual Expertise Network (PEN):
The Perceptual Expertise Network (PEN):

A group of 10 researchers from Psychology, Neuroscience, Neuropsychology and Computer Science

The goal of our network was to understand the learning mechanisms and representations underlying visual expertise

Our first meetings were used to establish a common vocabulary, and to synchronize our research around a set of common questions, rather than focus on our techniques
Temporal Dynamics of Learning

The Vision
Temporal Dynamics of Learning

The Vision
Temporal Dynamics of Learning

The Vision
The Vision

Sensorimotor Network

Network Goal

To understand the temporal dynamics of sensory perceptual learning and motor learning, from biological learning rules at synapses to human behavior.

Precise timing is a critical feature of natural sensory stimuli, and of movements, and is actively learned.

We will study the synaptic mechanisms, neural systems, and computational strategies used by the brain to implement temporal features of sensory perceptual and motor learning.
Temporal Dynamics of Learning

The Vision

Interacting Memory Systems Network

Network Goals

How does a learner abstract the **temporal structure** of the environment?

How does the brain arbitrate control across the **multiple memory systems** involved in learning?

How does the **timing** of training and **testing** regimes affect the rate of **learning** and long-term **retention**?

We will study brain **synaptic mechanisms**, **electrophysiological properties**, **computational strategies**, and **neuroimaging correlates**, in order to explain the temporal features that underlie efficient behavioral performance.
Perceptual Expertise Network

Network Goals
To relate the short-term dynamics of perception and perceptual decisions to the long-term dynamics of expert learning, and to exploit that understanding to significantly improve learning.

We will take a multidisciplinary approach to studying how perceptual expertise changes as a function of time and across experience.
Social Interaction Network

**Network Goals**

What are the effects of *timing* on social interactions and social learning?

How does the brain organize behavior in *real time*?

What are the neural mechanisms engaged during *learning* in a *social context*?

We will study *active learning* and *teaching* as well as *real-time* social interaction.
The Network-of-Networks Solution

UC San Diego
Rutgers University
Vanderbilt University
UC Berkeley
University of Colorado
The Salk Institute
Queensland University
Victoria University
Brown University
Carnegie-Melon University
Yale University
San Diego State University

SensoriMotor Network
Social Interaction Network
Interacting Memory Systems
Perceptual Expertise Network

Mathematics
Physics
Machine Learning
Robotics
Computer Science
Computational Neuroscience
Neuroscience
Cognitive Science
Linguistics
Neuropsychology
Cognitive Psychology
Developmental Psychology
Learning Theory
Education

Temporal Dynamics of Learning

The Vision
But...this wasn’t good enough: NSF wanted *Initiatives*!

- Cross-cutting projects that *all* networks could work on.
- Initiatives that would cause us to synchronize research *across* the center
- Initiatives that would answer the Big Questions
The First **TDLC** Initiative

1. **What is a SIP??**

   Is it

   a): a small drink of water?
   b): a Strategy for Initiative Planning?
   c): A way for NSF to torture us?
   d): A Strategic and Implementation Plan?

   Actual answer: All of the above!
The Actual **TDLC** Initiatives

1. How is temporal information about the world learned, and how do the temporal dynamics of the world influence learning? [INPUT]

2. How do the dynamics intrinsic to brain cells, brain systems, and behavior influence learning? [CENTRAL PROCESSING]

3. How are the temporal structures of movement and sampling the environment learned? [OUTPUT]

4. What mechanisms determine the time course of learning itself? What general principles explain the dynamics of learning across multiple scales and domains? [THEORY]
Initiative/Network threading

• Each research network has a coherent focus; the initiatives weave them together:
• The goal of network meetings is to synchronize research *within networks*
  – By bringing together researchers from multiple domains, the research becomes *problem oriented* rather than *technique oriented*.
  – At PEN’s early meetings, we designed experiments that could be run using the same stimuli in humans, monkeys, and neural nets: we *synchronized our research!*
• Alternating with network meetings, the goal of initiative meetings is to synchronize research *between networks*. 
Where will we be in Five Years?
Out of funding?
Where will we be in Five Years?

Deliverables

• *A Science of the Temporal Dynamics of Learning.*

• We need to *understand* the temporal dynamics of learning in order to *manipulate* it towards better learning outcomes.

• The Fast ForWord example I described here is the prototype.
Deliverables: New Tools for Education

- With our partner Scientific Learning Corporation, use the FastForWord platform to translate our research into the classroom: e.g., Fast ForMath, FastForMemory...

- Let’s Face It!, a program for teaching kids with social deficits to read faces.

- RUBI, an educational robot suitable for preschools.
Deliverables: New Tools for Research

• The network of networks structure:
  • Scalability
  • Collaboration
  • Shared facilities
  • Bridge postdocs
  • Shared philosophy
Temporal Dynamics of Learning

Deliverables: New Tools for Research

- A **Data Sharing Facility** to provide support for management of joint research data, and a state-of-the-art **Data GRID** at the NSF-sponsored San Diego Supercomputer Center to allow data mining, temporal alignment of imaging, spike data and behavioral data from multiple sites.

- This will become a resource for **all** Centers

<table>
<thead>
<tr>
<th>Storage Resource Broker Collections at SDSC (8/2/2005)</th>
<th>TBs of data stored</th>
<th>Number of files (millions)</th>
<th>Users with ACLs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data Grid</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NSF/ITR - National Virtual Observatory</td>
<td>53.9</td>
<td>9.5</td>
<td>100</td>
</tr>
<tr>
<td>NSF - National Partnership for Advanced Computational Infrastructure</td>
<td>36.1</td>
<td>7.5</td>
<td>380</td>
</tr>
<tr>
<td>Static collections – Hayden planetarium</td>
<td>8.0</td>
<td>0.2</td>
<td>227</td>
</tr>
<tr>
<td>Pzone – public collections</td>
<td>13.0</td>
<td>6.7</td>
<td>68</td>
</tr>
<tr>
<td>NSF/NPACI - Biology and Environmental collections</td>
<td>40.1</td>
<td>0.1</td>
<td>67</td>
</tr>
<tr>
<td>NSF/NPACI – Joint Center for Structural Genomics</td>
<td>15.7</td>
<td>1.6</td>
<td>55</td>
</tr>
<tr>
<td>NSF - TeraGrid, ENZO Cosmology simulations</td>
<td>176.7</td>
<td>2.1</td>
<td>3,267</td>
</tr>
<tr>
<td>NIH - Biomedical Informatics Research Network</td>
<td>10.6</td>
<td>7.6</td>
<td>303</td>
</tr>
<tr>
<td><strong>Digital Library</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NSF/NPACI - Long Term Ecological Reserve</td>
<td>0.3</td>
<td>0.01</td>
<td>36</td>
</tr>
<tr>
<td>NSF/NPACI - Grid Portal</td>
<td>2.6</td>
<td>0.05</td>
<td>460</td>
</tr>
<tr>
<td>NIH - Alliance for Cell Signaling microarray data</td>
<td>0.7</td>
<td>0.08</td>
<td>21</td>
</tr>
<tr>
<td>NSF - National Science Digital Library SIO Explorer collection</td>
<td>2.7</td>
<td>1.1</td>
<td>27</td>
</tr>
<tr>
<td>NSF/ITR - Southern California Earthquake Center</td>
<td>131.0</td>
<td>2.7</td>
<td>73</td>
</tr>
<tr>
<td><strong>Persistent Archive</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NHPRC Persistent Archive Testbed (Kentucky, Ohio, Michigan, Minnesota)</td>
<td>0.1</td>
<td>0.4</td>
<td>28</td>
</tr>
<tr>
<td>UCSD Libraries archive</td>
<td>4.1</td>
<td>0.4</td>
<td>29</td>
</tr>
<tr>
<td>NARA- Research Prototype Persistent Archive</td>
<td>1.5</td>
<td>0.9</td>
<td>58</td>
</tr>
<tr>
<td>NSF - National Science Digital Library persistent archive</td>
<td>3.6</td>
<td>27.0</td>
<td>136</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>501 TB</td>
<td>68 million</td>
<td>5,335</td>
</tr>
</tbody>
</table>
Deliverables: New Tools for Research

- A **Motion capture Facility** to provide state-of-the-art equipment and software for simultaneous capture and analysis of multiple fine-scale temporal actions and interactions.

  - Eye movement
  - Muscle activity
  - Hand movement
  - Body movement
  - Facial Expression
  - Force
  - Haptics
Deliverables: New Tools for Research

- A **Brain Dynamics Facility** to provide state-of-the-art simultaneous EEG/fMRI analysis and hardware for fine scale temporal and spatial resolution of brain activity to bring off the next revolution in brain imaging.
Deliverables: New Tools for Outreach

- **The Science Network Web TV Channel** to broadcast “Town Meetings” between scientists, policy makers, parents, teachers and the public and help promote a better understanding of science in the US and the world.

- All of the Science of Learning Centers will be able to use The Science Network to publicize their science.
Deliverables: More Diverse Scholars

- UCSD’s **Preuss School**: 100% school lunch program kids, 91% accepted to four-year colleges: They are in our labs, and they helped to give RUBI locomotion.
- **Reach for Tomorrow**: Inner city kids come to campus and are inspired to attend college
- **Faculty Partners Program**: Building pipelines to minority institutions
Summary

• The time is right to study time!
• We have an excellent team of world-class researchers.
• We have a well-designed and flexible organizational structure.
• We have a unity of vision.
Summary

• We are prepared to train a diverse group of scientific leaders for the 21st century.
• We are committed to making our research relevant to the classroom.
Life passes in milliseconds, but what we learn in those milliseconds changes us for life.
Temporal Dynamics of Learning

The Vision
Managing and Evaluating Our Center

Our home will be at CalIT2 which uses a management model based on the Apollo Program.

Thorough Multi-layered Evaluation Plan

Andy Porter of Vanderbilt will advise us on evaluation:
And he advised us to use Brenda Turnbull!

Our External Advisory Board will evaluate our scientific progress.