CSC 595 - Research Skills

Generating Ideas #3: Cross-Disciplinary Thinking

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Examples of Entire Fields that are Interdisciplinary

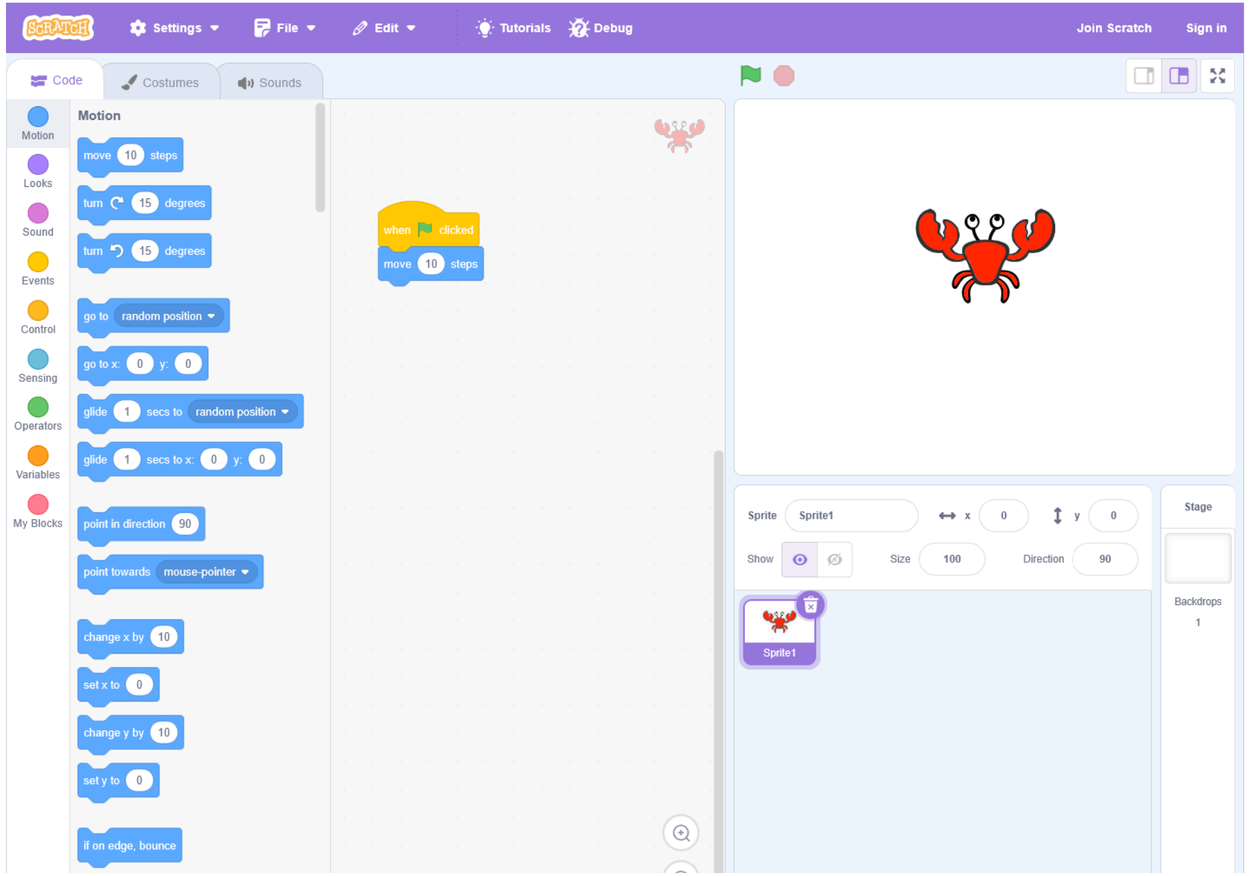
- Human-Computer Interaction (spans many areas)
  - Top conference: CHI
- Bioinformatics = Biology + Computer Science
  - Top conference: RECOMB
- Computational Linguistics/Natural Language Processing = Linguistics + Computer Science
  - Top conferences: ACL, EMNLP, NAACL
- Music Information Retrieval = Music + Computer Science
  - Top conference: ISMIR

Examples of Entire Fields that are Interdisciplinary

- Cognitive Science (spans many areas)
- Computational Neuroscience = Neuroscience + Computer Science
  - Top conference: COSYNE
- Economics and Computation = Economics + Computer Science
  - Top conference: EC
- Network/Internet Economics = Economics + Computer Science
  - Top conference: WINE

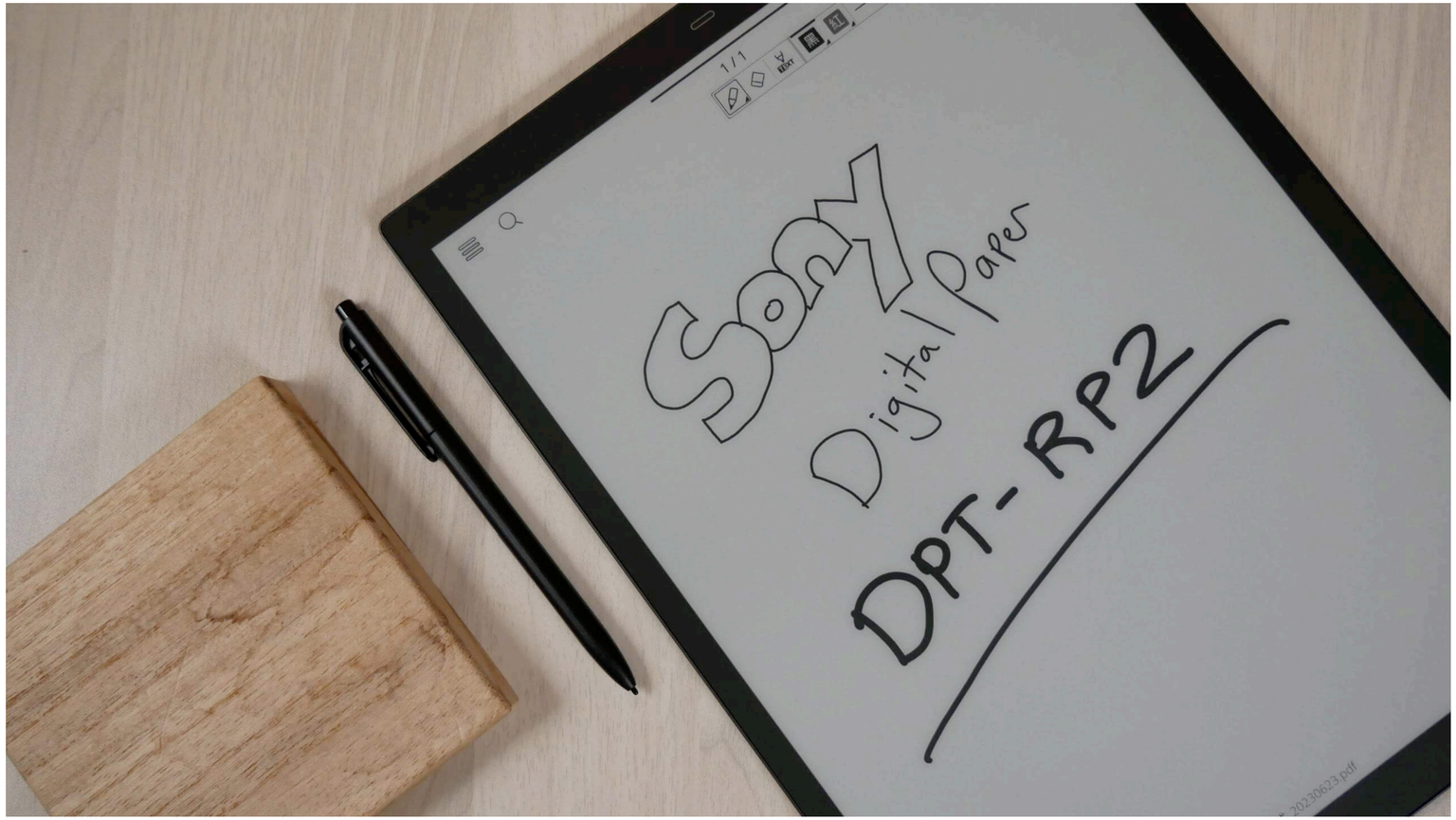
Examples of Successful Cross-Disciplinary Research

- **Scratch:** From CS Education + HCI + Programming Languages



Examples of Successful Cross-Disciplinary Research

- **E Ink:** from Jacobsen (physicist) + Comiskey (math major) + Albert (mechanical engineer)



Examples of Successful Cross-Disciplinary Research

- **Spam Filtering:** from Networking + NLP + Machine Learning
- **Quantum Computers:** from CS + Physics
- **Multiple Sequence Alignment problem:** From CS + Biology
  - For constructing phylogenetic tree
- **Genetic Algorithms:** from CS (Machine Learning) + Biology

Examples of Cross-Disciplinary research

- Chatbots: from Computational Linguistics/NLP (CS + Linguistics)

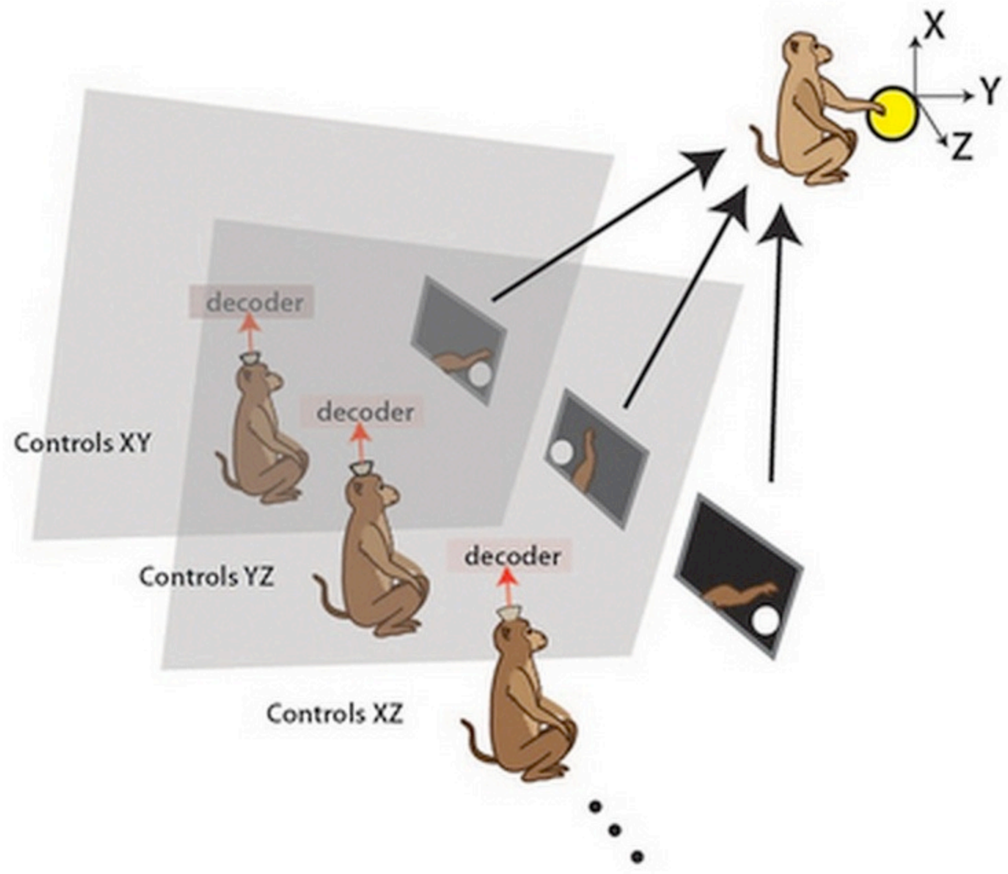
```
  Welcome to
                 EEEEEE  LL      IIII   ZZZZZZ   AAAAA
                 EE      LL       II       ZZ   AA   AA
                 EEEEE   LL       II     ZZZ    AAAAAAA
                 EE      LL       II    ZZ      AA   AA
                 EEEEEE  LLLLLL  IIII ZZZZZZ    AA   AA

  Eliza is a mock Rogerian psychotherapist.
  The original program was described by Joseph Weizenbaum in 1966.
  This implementation by Norbert Landsteiner 2005.


ELIZA: Is something troubling you ?
YOU:   Men are all alike.
ELIZA: What is the connection, do you suppose ?
YOU:   They're always bugging us about something or other.
ELIZA: Can you think of a specific example ?
YOU:   Well, my boyfriend made me come here.
ELIZA: Is it important to you that your boyfriend made you come here ?
YOU:   He says I'm depressed much of the time.
ELIZA: I am sorry to hear that you are depressed.
YOU:   It's true. I am unhappy.
ELIZA: Can you explain what made you unhappy ?
YOU:
```

Examples of Cross-Disciplinary research

- Brain-computer interfaces: from CS + Neuroscience
  - Technology to help patients with Amyotrophic Lateral Sclerosis



Remember the role of research

- We aren't doing research to make products; industry is much better equipped to do that
- We do research to come up with novel (inventive!) ways of solving problems.
  Best-case: REVOLUTIONARY ideas
- Industry is short-sighted: suffers from myopia (some exceptions, but largely true)
- Research looks to the future; need not be inhibited by the constraints we have today. Enough to come up with a concept. No need to worry about mass-production within the next 2 years.
    - So, can think more like a child. Imagine the world we want, rather than concretely obtaining a somewhat better world within 2 years.

Why Cross-Disciplinary Thinking?

- Real-world problems are messy. Often call for Cross-Disciplinary RESEARCH

research to solve a problem in one area by drawing from other areas

- Example - Climate change:
  - physics, chemistry, CS (climate modeling)
  - game theory (how to encourage people behave in a good way, setting up incentives)

Why Cross-Disciplinary Thinking?

- Real-world problems are messy. Often call for Cross-Disciplinary RESEARCH

research to solve a problem in one area by drawing from other areas

- Example - Water contamination:
  - economics, also business (industry incentives related to use of plastics)
  - law
  - chemistry
  - industrial engineering (processes for decontamination)

Why Cross-Disciplinary Thinking?

- Recall: Research Patterns
  - Cross-disciplinary thinking is a MAJOR research pattern for generating new ideas, even if those ideas are just brought to bear on problems within your own field

Pro-Tips for Cross-Disciplinary Researchers

- Have some expertise of your own. Difficult to find connections without a strong base
- Give focused talks. Even if work is cross-disciplinary, target a specific audience
- Pick a home
  - This is the community that recognizes you, that supports you
  - The place where you start out and build your name

Talk to people outside your area

- Try meeting grad students from different departments. Occasionally eat lunch with them
- Try going to a happy hour
- Talk to classmates in this class (we span a lot of computer science!)
- “What’s in it for me?”
  - Hearing about people’s (research…) problems may spark new ideas within your own area
  - Telling people about one of your problems may lead to them suggesting new ways of thinking about the problem

How to form connections with people outside your area?

- Concretely: look for “mixer” events
  - CS (or Engineering/CS) + Chemistry
  - CS + Sociology
  - CS + Philosophy
- Extra-curricular activities
  - Dance group, Martial arts group
  - Being connected with “real” people can provide fresh perspectives

Recent example proving these mixers exist

How to form connections with people outside your area?

Do internships!

summer is ideal (usually more grad student interns around. why?)

Side benefits:

- Change of scenery is good for creativity (new stimuli, break out of old habits)
- Extra money
- Taking break from usual research is good. Come back with fresh mind

Language Issues

- Problem: Need to be able to understand others, even when their work is described in their field's language rather than yours

- Solution:
  - Do your part. Practice explaining your problems in a language that someone smart (but from another field) can understand.
  - This is a form of practicing communication, but with the potential for a big payoff (you might get new ideas in return!)
  - Do some reading to get very basic expertise (minimal language) of the other area

Case Study 1

Nobel Prize in Chemistry 2024

© Nobel Prize Outreach. Photo: Clément Morin

David Baker

Prize share: 1/2

© Nobel Prize Outreach. Photo: Clément Morin

Demis Hassabis

Prize share: 1/4

© Nobel Prize Outreach. Photo: Clément Morin

John Jumper

Prize share: 1/4

Case Study 1

David Baker

Field: Biochemistry

Fun facts:

- Started in philosophy and social science.
  Switched to cell biology

Case Study 1

Demis Hassabis

Fields: CS, Cognitive Neuroscience

Fun facts:

- Playing chess at 4, master level at 13
- Worked at many game companies (including one just before undergrad)
- Fundamental work in neuroscience: improved understanding of episodic memory

Case Study 1

John Jumper

Fields: Biophysics, Artificial Intelligence

Fun facts:

- Started in Physics and Math
- Two Master's: Theoretical Condensed Matter Physics AND Theoretical Chemistry
- PhD in Theoretical Physics
- Got interested in proteins, and computing, when working at a company

Case Study 1

How did the cross-disciplinary work happen?

(1) Baker had been working on Rosetta: feed in target 3D structure, go backwards to “predict” an amino acid sequence that could fold into that structure

(2) Hassabis’s team produced AlphaFold: got 60% accuracy at CASP (next best was 40%)

(3) Jumper joins. Brings knowledge of proteins to improve AlphaFold.
In parallel, DeepMind switches to Transformers.
Result: AlphaFold2. Achieves 90% accuracy. Competitive with X-ray crystallography!

(4) Baker saw importance of AlphaFold2. Incorporated it into Rosetta. Achieved greater success.

- Biochemistry benefits Computer Science AND Computer Science benefits Biochemistry

- All for the sake of Biochemistry

Case Study 2

Nobel Prize in Physics 2024

© Nobel Prize Outreach. Photo: Nanaka Adachi

John J. Hopfield

Prize share: 1/2

© Nobel Prize Outreach. Photo: Clément Morin

Geoffrey Hinton

Prize share: 1/2

Case Study 2

John Hopfield

Fields: Physics (and Chemistry, Biology)

Fun facts:

PhD in Physics

Path:

Bell Labs

→ Professor of Physics

→ Professor of Chemistry and Biology

→ Professor of Molecular Biology

Co-founded PhD program in Computation and Neural Systems at Caltech

Case Study 2

Geoffrey Hinton

Fields: Experimental Psychology, Artificial Intelligence

Fun facts:

- Switched fields many times in undergrad
- Moved to Canada because unhappy with US's military funding of AI research
- Great-great-grandson of George Boole

Case Study 2 (Hopfield)

How did the cross-disciplinary work happen?

(1) Hopfield was using background in theoretical physics to explore problems in molecular biology

(2) Hopfield invited to neuroscience meeting, learns about research into structure of the brain. Starts thinking about dynamics of simple neural networks

(3) Hopfield moves from Princeton (Physics Professor) to CalTech (Chemistry and Biology Professor)

(4) Hopfield comes up with network where each node (atom) has a spin, and neighboring nodes influence each other (spin glass system)

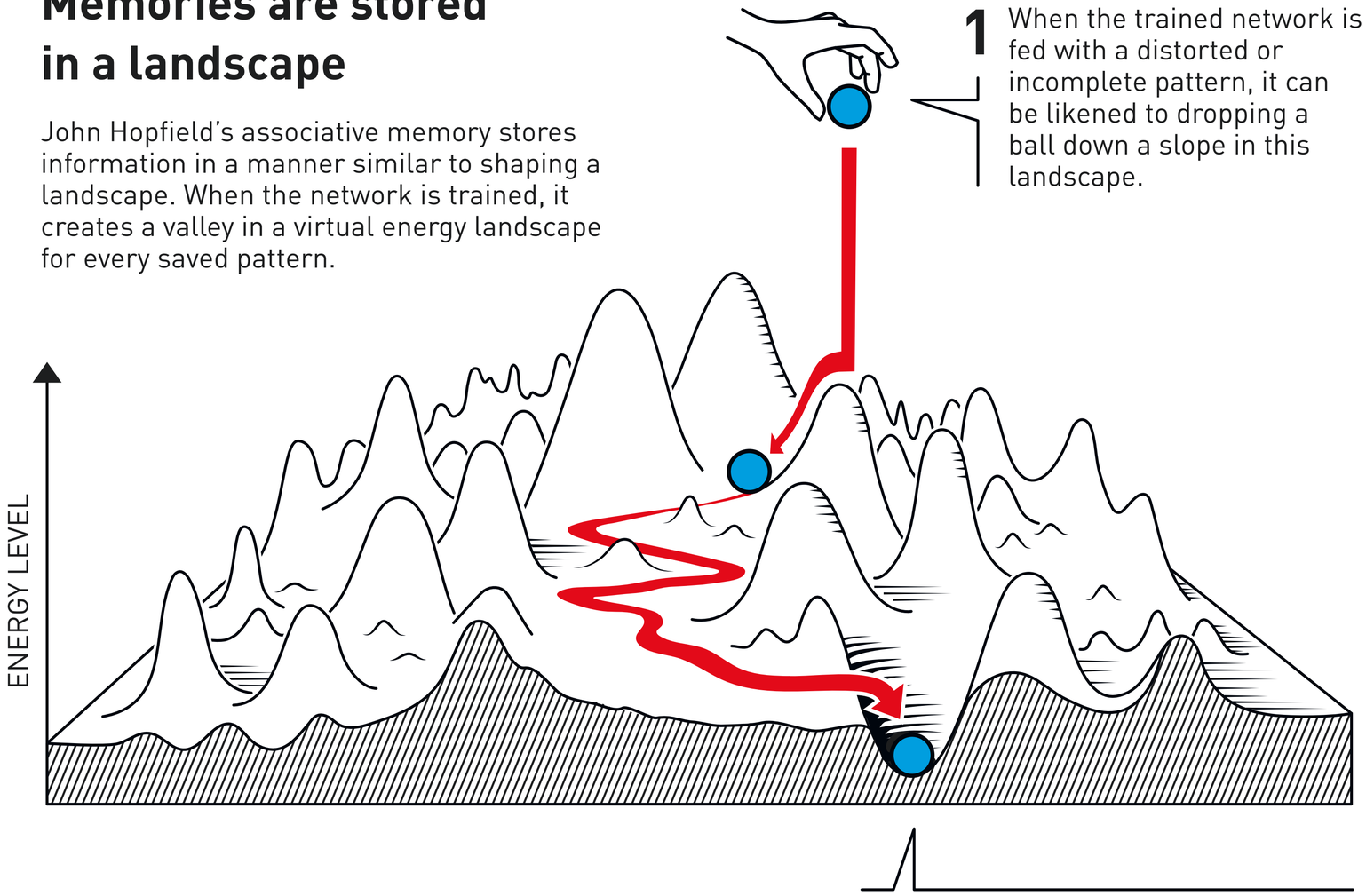
(5) Image is fed into network. Connections are adjusted to low energy state, “saving” the image

(6) Fundamental research is ongoing even today on memory capacity of Modern Hopfield Networks

- Message: Physics benefits Artificial Intelligence

Memories are stored in a landscape

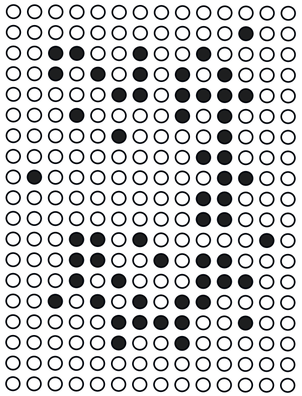
John Hopfield's associative memory stores information in a manner similar to shaping a landscape. When the network is trained, it creates a valley in a virtual energy landscape for every saved pattern.



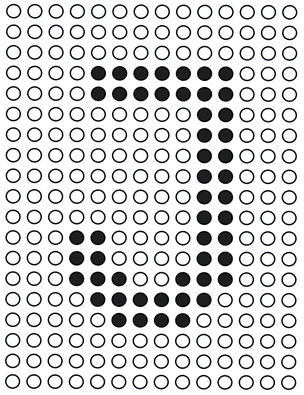
1 When the trained network is fed with a distorted or incomplete pattern, it can be likened to dropping a ball down a slope in this landscape.

2 The ball rolls until it reaches a place where it is surrounded by uphills. In the same way, the network makes its way towards lower energy and finds the closest saved pattern.

INPUT PATTERN



SAVED PATTERN



Case Study 2 (Hinton)

How did the cross-disciplinary work happen?

(1) Hinton came from experimental psychology and AI background

(2) Together with Terry Sejnowski (physics background, advisor was Hopfield), used ideas from statistical physics to invent Boltzmann Machine (later evolved to Restricted Boltzmann Machine)

(3) 1986: Hinton and co-authors demonstrated successful training via backpropagation

(4) Other advances happened within AI, but from the physics side… physics benefited from the use of artificial neural networks

- Message: Physics benefits Artificial Intelligence AND Artificial Intelligence benefits Physics