

Computational Thinking in the Sciences and Beyond

Jeannette M. Wing

Corporate Vice President, Microsoft Research

Microsoft Research
Asia Faculty Summit – Beijing China
30 October 2014

My Grand Vision

- **Computational thinking** will be a fundamental skill used by everyone in the world by the middle of the 21st Century.
 - Just like reading, writing, and arithmetic.
 - Incestuous: Computing and computers will enable the spread of computational thinking.
 - **In research:** scientists, engineers, ..., historians, artists
 - **In education:** K-12 students and teachers, undergrads, ...

J.M. Wing, "Computational Thinking," *CACM Viewpoint*, March 2006, pp. 33-35.
Paper off <http://www.cs.cmu.edu/~wing/>

What is Computational Thinking?

Computational thinking is the *thought processes* involved in formulating a problem and expressing its solution(s) in such a way that a computer—human or machine—can effectively carry out.

Computational Thinking, Philosophically

- Complements and combines mathematical and engineering thinking
 - C.T. draws on math as its foundations
 - But we are constrained by the physics of the underlying machine
 - C.T. draws on engineering since our systems interact with the real world
 - But we can build virtual worlds unconstrained by physical reality
- Ideas, not artifacts
 - It's not just the software and hardware that touch our daily lives, it will be the computational concepts we use to approach living.
- It's for everyone, everywhere

Sample Classes of Computational Concepts

- Algorithms
 - E.g., mergesort, binary search, string matching, clustering
- Data Structures
 - E.g., sequences, tables, trees, graphs, networks
- State Machines
 - E.g., finite automata, Turing machines
- Languages
 - E.g., regular expressions, ..., VDM, Z, ..., ML, Haskell, ..., Java, Python
- Logics and semantics
 - E.g., Hoare triples, temporal logic, modal logics, lambda calculus
- Heuristics
 - E.g., A* (best-first graph search), caching
- Control Structures
 - Parallel/sequential composition, iteration, recursion
- Communication
 - E.g., synchronous/asynchronous, broadcast/P2P, RPC, shared memory/message-passing
- Architectures
 - E.g., layered, hierarchical, pipeline, blackboard, feedback loop, client-

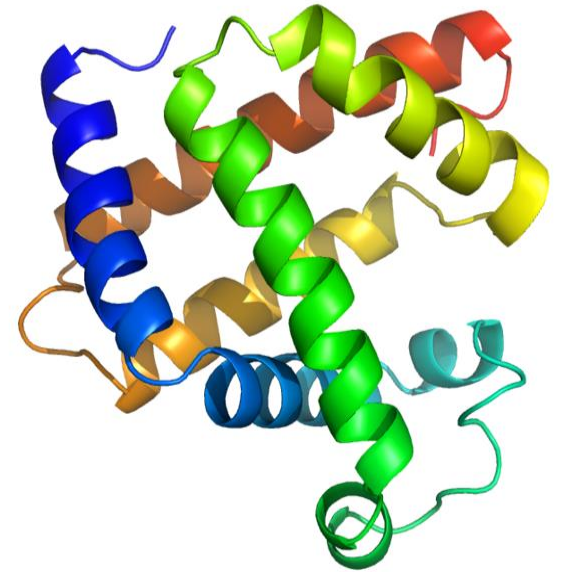
NOT

- Computer literacy, i.e., how to use Word and Excel or even Google or Bing
- Computer programming, i.e., beyond Java Programming 101

Examples of Computational Thinking in Other Disciplines

**One Discipline, Many Computational
Methods**

Computational Thinking in Biology

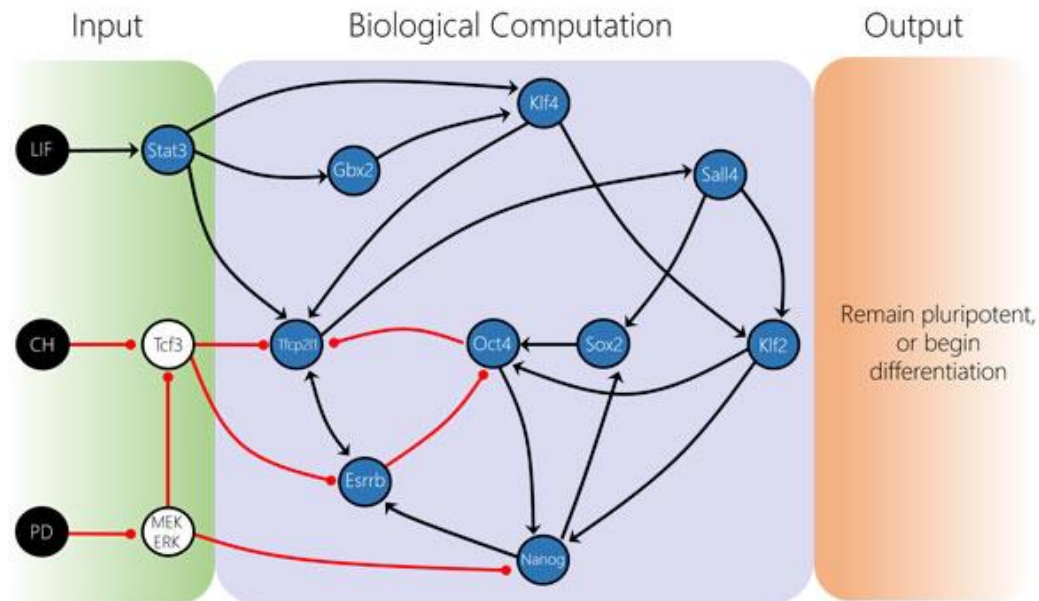


- Shotgun **algorithm** expedites sequencing of human genome
- **Abstract interpretation** in systems biology
- **Model checking** applied to arrhythmia, diabetes, pancreatic cancer
- DNA sequences are strings in a **language**
- **Boolean networks** approximate dynamics of biological networks
- Cells as a self-regulatory system are like **electronic circuits**
- **Process calculi** model interactions among molecules
- **Statecharts** used in developmental genetics
- Protein kinetics can be modeled as **computational processes**
- **Robot Adam** discovers role of 12 genes in yeast
- PageRank **algorithm** inspires ecological food web

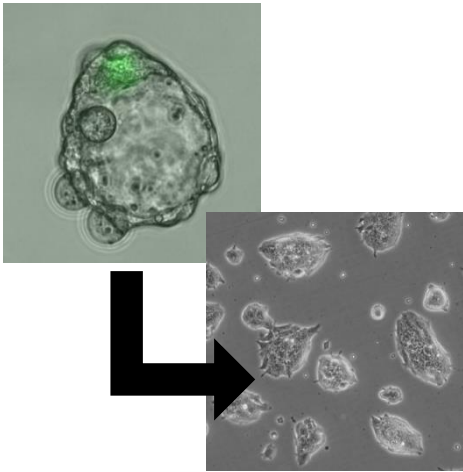
Insight: Models and languages for expressing computational processes are good for expressing the dynamics of biological processes.

Stem Cell Prediction

[Dunn et al., “Defining an essential transcription factor program for naïve pluripotency,” *Science*, June 2014, pp. 1156-1160]

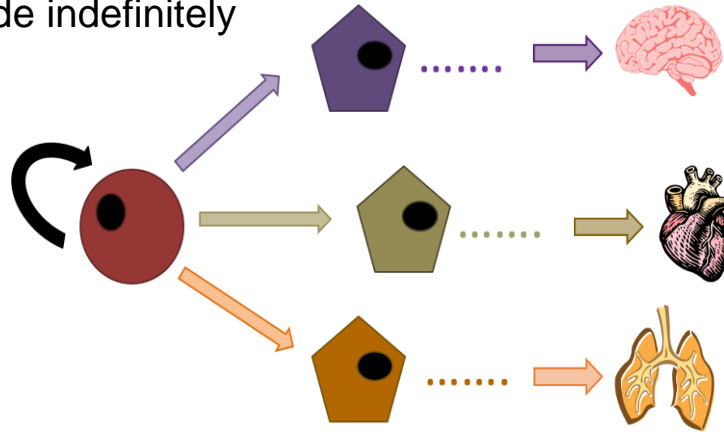


Embryonic Stem (ES) Cells

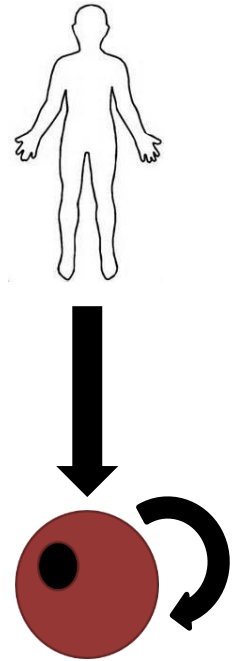


Transient in tissue:
A culture-dependent phenomenon

Self-renewing:
Divide indefinitely



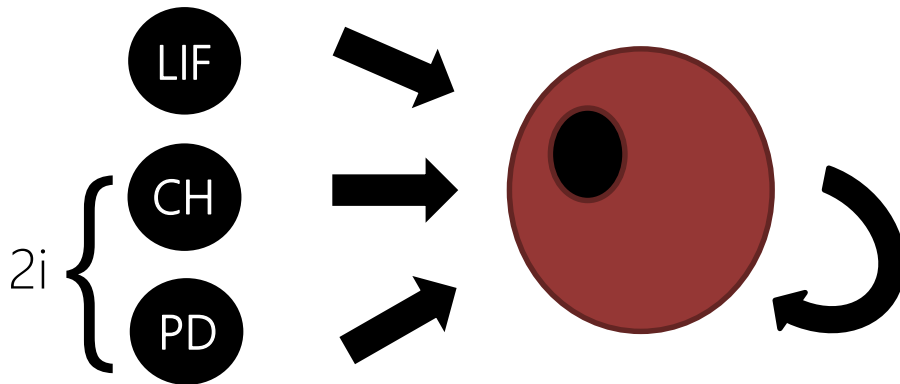
Pluripotent: Generate all adult cell types,
and can be re-injected back into the
developing embryo



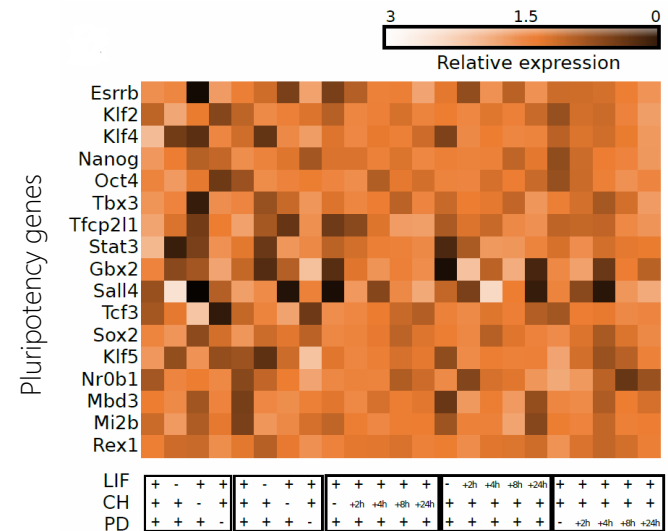
We can **reprogram** adult
cells to this state

Extrinsic Signals Control ES Cell Behaviour

Whether an ES cell will remain self-renewing, or differentiate towards an adult cell lineage depends on the signals that it receives.

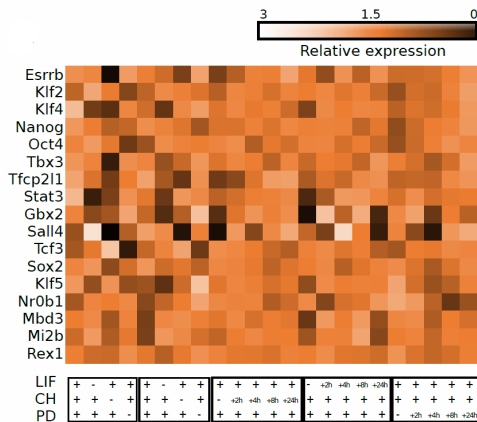


The signals required to sustain ES cells in culture have been progressively refined. Any two of LIF, CH and PD are sufficient.

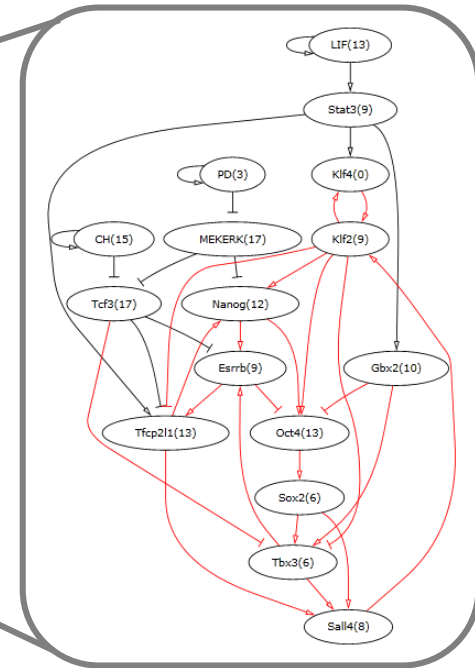
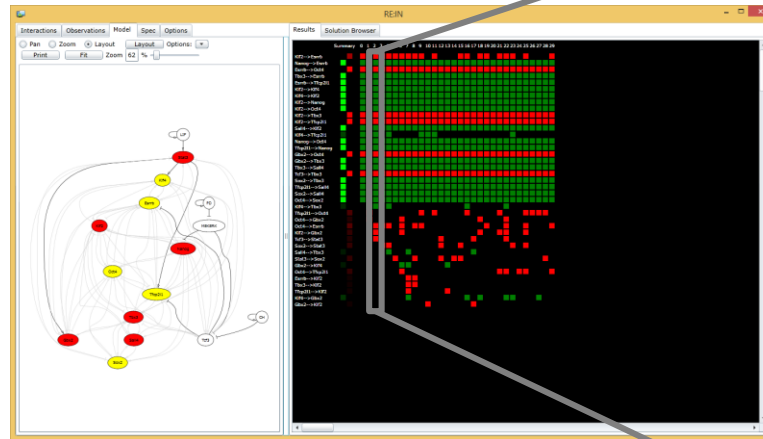
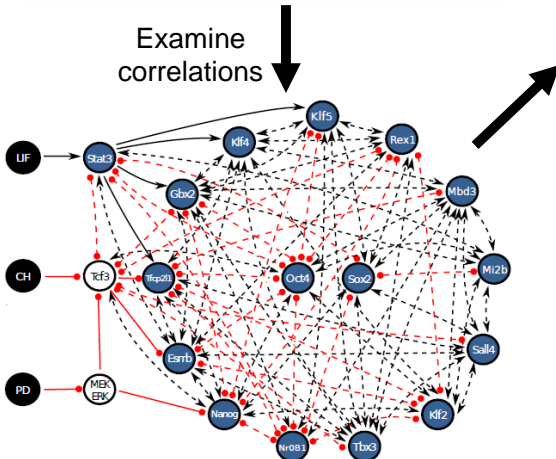


We can measure the expression of key genes under different combinations of signals to gain insight into the dynamic behavior of the system.

A Reasoning Engine for Interaction Networks



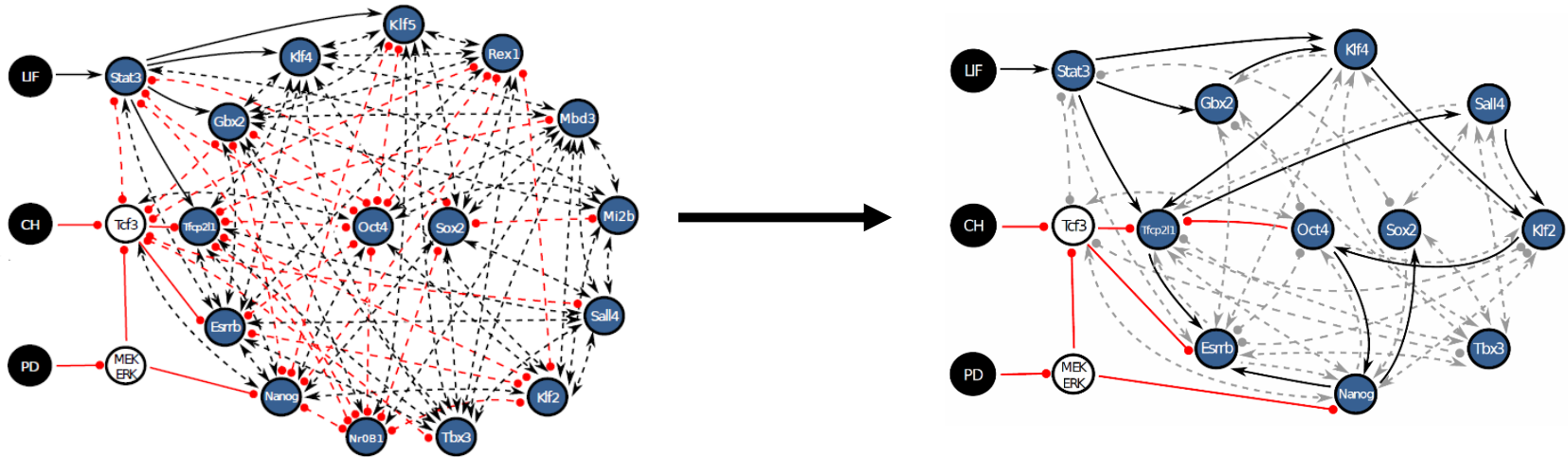
Examine correlations



IF (signalA AND signalB
AND NOT signalC OR ...)
THEN remain a stem cell
ELSE (IF NOT signalA ...)
differentiate

RE:IN is a tool built on Z3 that utilizes Satisfiability Modulo Theories to synthesize only those (out of 10^{43}) Boolean networks that provably satisfy experimental constraints.

Biological Computation in Stem Cells



- The set of possible models was constrained by experimentally-observed behaviours
- This set was used to make a large number (53) of non-intuitive predictions of the response of the network to genetic perturbations. These predictions were experimentally validated with over 70% accuracy rate.
- The highlighted interactions show the minimal set required to explain stem cell behaviour: **the essential program governing naïve pluripotency**

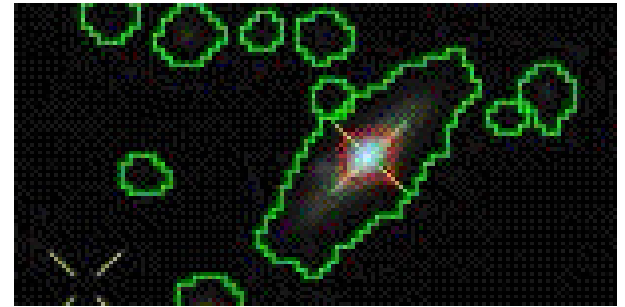
One Computational Method, Many Disciplines

Machine Learning has transformed the field of Statistics.

Machine Learning in the Sciences

Astronomy

- Brown dwarfs and fossil galaxies discovery via machine learning, data mining, data federation
- Very large multi-dimensional datasets analysis using KD-trees



Credit: SDSS

Medicine



- Anti-inflammatory drugs
- Chronic hepatitis
- Mammograms
- Renal and respiratory failure

Credit: LiveScience

Meteorology

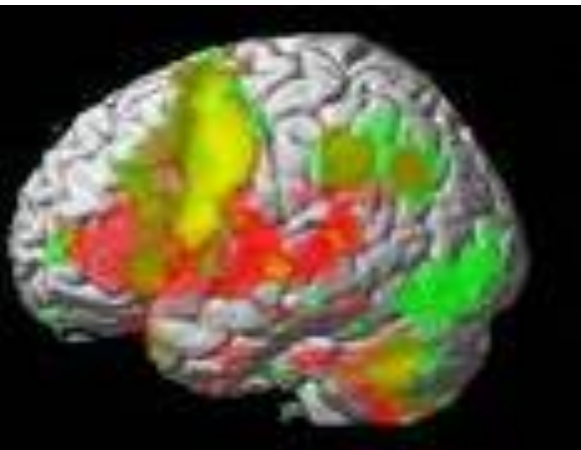
- Tornado formation



© Copyright 2004 Eric Nguyen

Neurosciences

- fMRI data analysis to understand language via machine learning



Fighting Spam and Fighting HIV



Spammers mutate their messages to work around filters

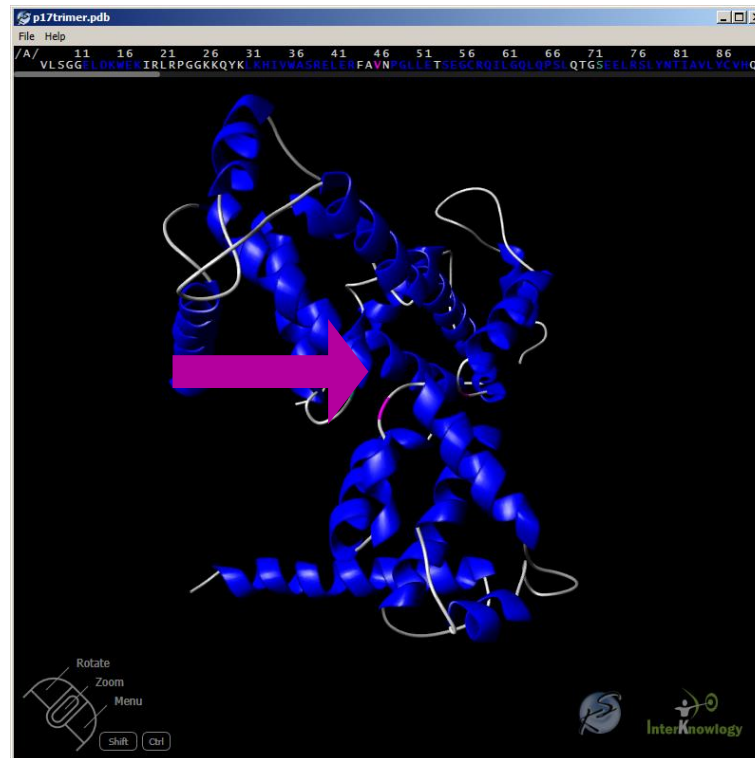
Solution: Go after the weak link



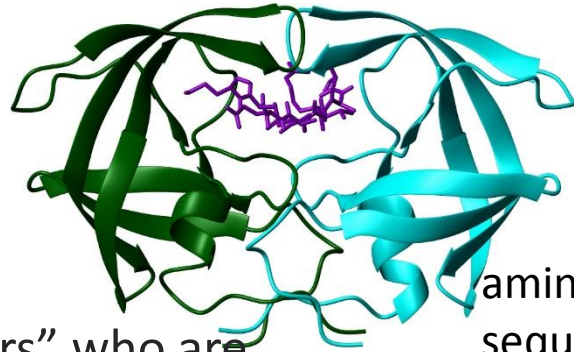
HIV mutates to avoid attack by immune system

Solution: Go after the weak link

Strategy: Identify vulnerable regions on HIV and create a vaccine that directs the immune system to target those regions



Finding Vulnerable Regions

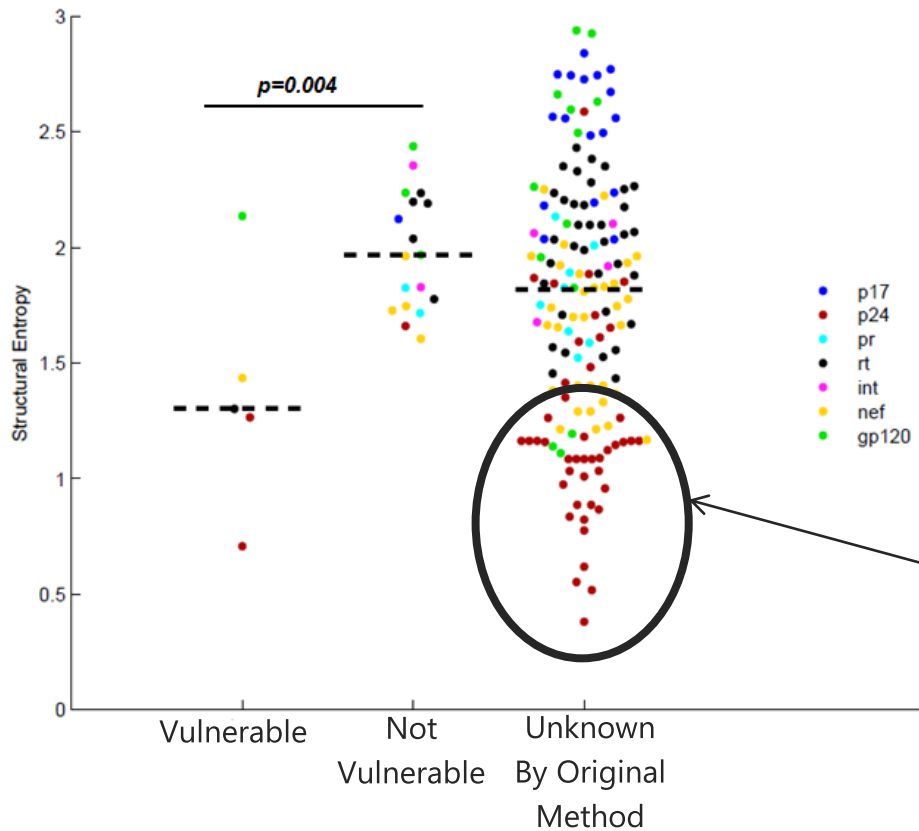


- Identify a set of “controllers” who are infected with HIV, but don’t get very sick
- Look for differences between where immune systems of controllers vs where those of normal people are attacking HIV
- These differences point to the vulnerable regions

amino acid sequence	protein	begin	end
KAFSPEVIPMF	p24	30	40
RLRDLLLIVTR	gp41	259	269
GIPHPAGLK	pr	192	200
HTQGYFPDW	nef	116	124
AEAMSQVTNS	p2	1	10
SAEPVPLQL	rev	67	75
QAISPRTLNAW	p24	13	23
RIKQIINMW	gp120	419	427

From data from hundreds of controllers and non-controllers, machine learning helped identified 8 regions of HIV proteins where controllers are much more likely to attack.

Finding More Vulnerable Regions



Use in silico prediction under the assumption that vulnerable regions are where the amino acid changes protein stability (increases “structural entropy”)

Estimate protein stability with simulations using the FoldX algorithm

These regions are new candidate vulnerable regions.

Machine Learning Everywhere



Credit Cards



Supermarkets



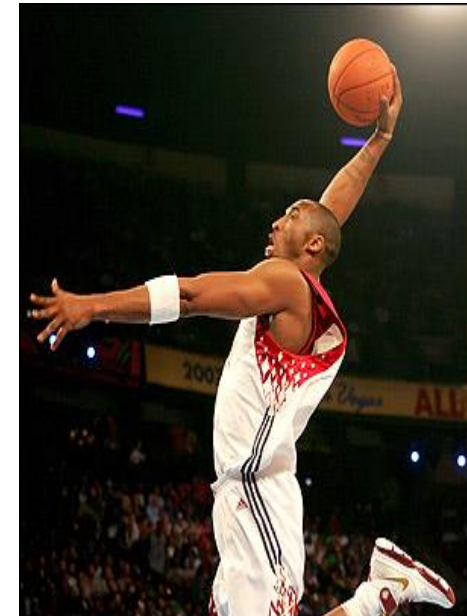
Wall Street



Entertainment:
Shopping, Music, Travel



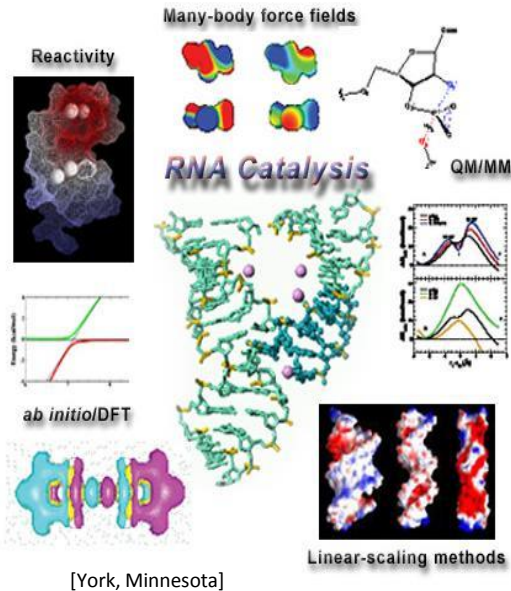
Sports



Computational Thinking in the Sciences and Beyond

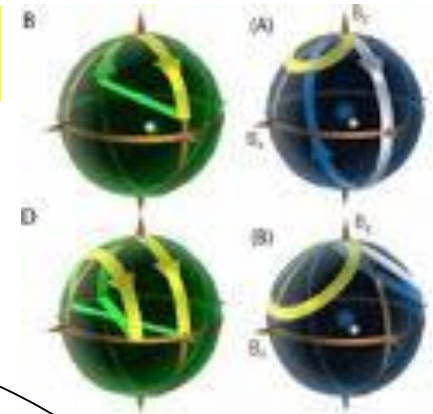
Computational Thinking in Other Sciences

Chemistry



- Atomistic calculations are used to explore chemical phenomena
- Optimization and searching algorithms identify best chemicals for improving reaction conditions to improve yields

Physics



- Adiabatic quantum computing: How quickly is convergence?
- Genetic algorithms discover laws of physics.

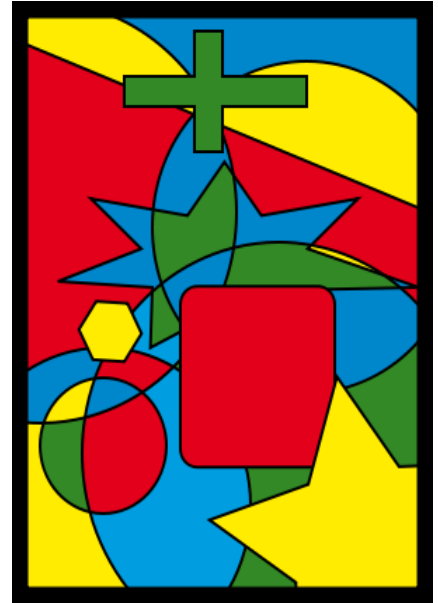
Geosciences

- Abstractions for Sky, Sea, Ice, Land, Life, People, etc.
 - Hierarchical, composable, modular, traceability, allowing multiple projections along any dimension, data element, or query
- Cornell's NSF Expedition on Computational Sustainability



Computational Thinking in Math and Engineering

Mathematics



Credit: Wikipedia

- Discovering E8 Lie Group:
18 mathematicians, 4 years and 77 hours of
supercomputer time (200 billion numbers).
Profound implications for physics (string theory)
- Four-color theorem proof

Credit: Wikipedia

Engineering (electrical, civil, mechanical, aero & astro,...)

Credit: Boeing



- Calculating higher order terms implies more precision,
which implies reducing weight, waste, costs in fabricati
- Boeing 777 tested via computer simulation alone,
not in a wind tunnel
- Hybrid automata for modeling and analyzing
cyber-physical systems

Computational Thinking for Society

Microsoft Digital Advertising Solutions

Economics



- Automated mechanism design underlies electronic commerce, e.g., ad placement, on-line auctions, kidney exchange
- Internet marketplace requires revisiting Nash equilibria model
- Use intractability for voting schemes to circumvent impossibility results

- Inventions discovered through automated search are patentable
- Stanford CL approaches include AI, temporal logic, state machines, process algebras, Petri nets
- POIROT Project on fraud investigation is creating a detailed ontology of European law
- Sherlock Project on crime scene investigation

Law



Healthcare

- Algorithmic medicine
- Software design principles and debugging applied to prescriptions of painkillers
- ONC SHARP Program, NSF Smart Health and Wellness Program, NITRD Senior Steering Group on Health IT



Fast and Accurate Decision-Making

2012 Xbox

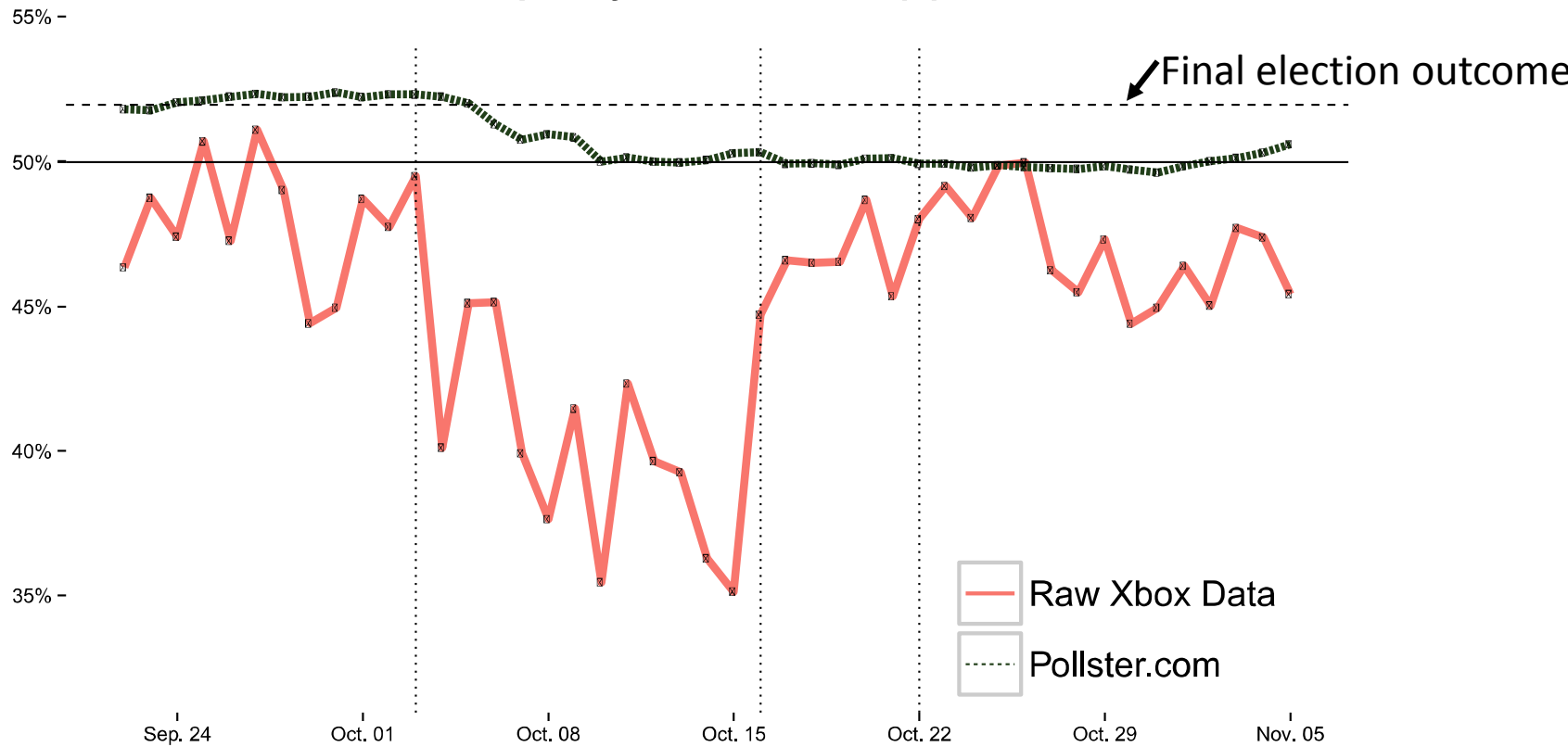
- Polling daily and during live debates
- 350k respondents: age, race, gender, state, edu, party id, ideology, previous votes, registration
- 750k polls in 45 days
- 30,000 respondents 5 or more polls
- Data and engagement great, but accuracy?

The screenshot shows the TIME Tech website interface. At the top, there's a navigation bar with categories like NEWSFEED, U.S., POLITICS, WORLD, BUSINESS, TECH, HEALTH, SCIENCE, ENTERTAINMENT, STYLE, SPORTS, OPINION, and PHOTOS. Below this is a search bar and social media icons. The main content area features a large poll titled "Obama Expected to Win Ohio, Say YouGov/Xbox Poll Respondents" by Matt Peckham, dated Nov. 02, 2012. The poll question is "If the 2012 presidential election were being held today, who would you vote for?" with options: Barack Obama, Mitt Romney, Other, and Undecided. The poll is presented on a screen with a blue and red background, and the Xbox LIVE logo is visible in the bottom right corner. To the right of the poll is a sidebar with an advertisement for flights from JFK to Palm Springs and a "MORE ON TIME" section with several article thumbnails.

Cite: Forecasting elections with non-representative polls; Gelman, Goel, Rothschild, and Wang (2014)

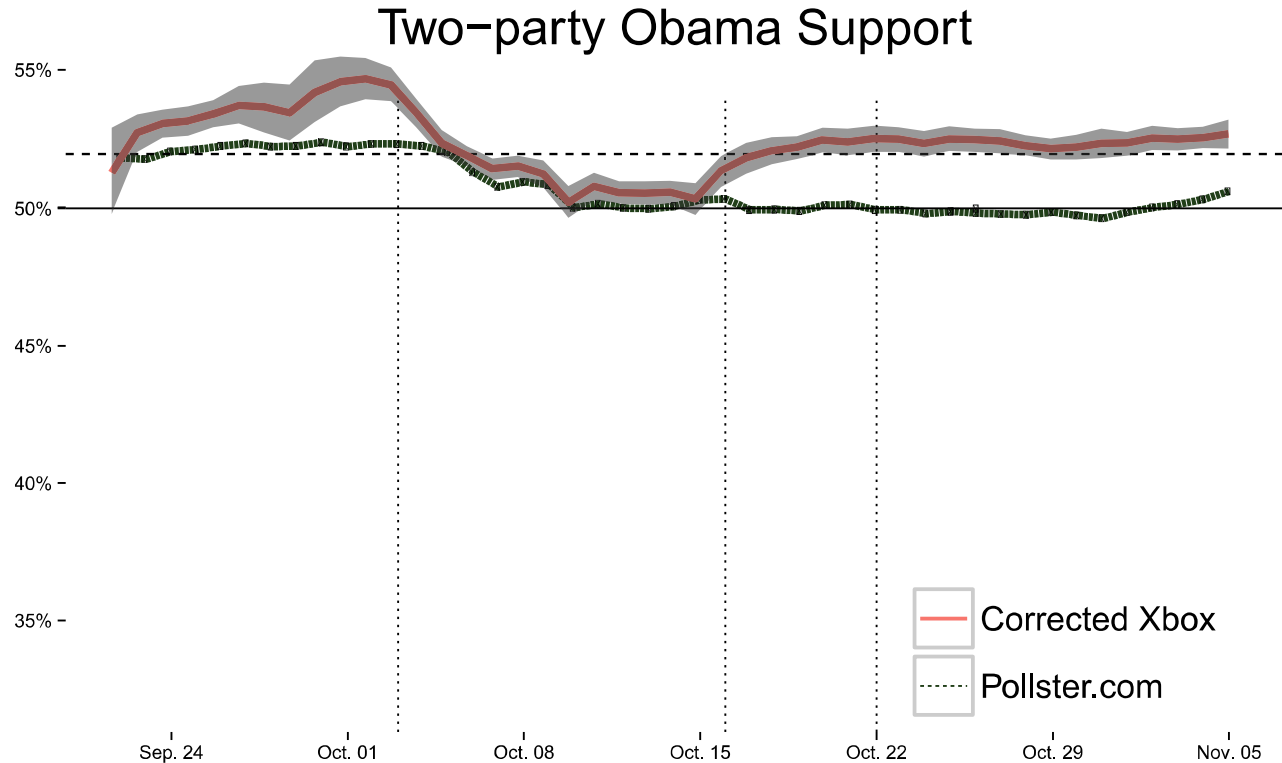
Data Collection

Two-party Obama Support



Cite: Forecasting elections with non-representative polls; Gelman, Goel, Rothschild, and Wang (2014)

Data Analytics



Cite: Forecasting elections with non-representative polls; Gelman, Goel, Rothschild, and Wang (2014)

Use convex optimization to keep millions of interrelated predictions consistent

2014 World Cup

Microsoft's Cortana Has Correctly Predicted Every World Cup Elimination Round Outcome

Jul 2, 2014, 11:42 AM ET
By ALYSSA NEWCOMB



Fifa World Cup 2014: Microsoft beats Google and Siri in predictions

By Joseph George
Published Tuesday, July 15, 2014

It was Paul the Octopus in 2010, but this time around, it is Microsoft's Cortana that has emerged winner in predicting World Cup results. Cortana, powered by Bing, got almost all the results correct except for one, thereby overtaking both Google and Apple's Siri.

"Thanks to Bing, Cortana has accurately predicted the winner in 15 out of 16 games," said the latest blog post by Windows.

Bing launched its Bing Predicts ahead of the world Cup and got 100 percent of matches and final elimination rounds correct. Cortana picked Brazil as the winner.

Microsoft's Cortana Has Predicted Every Elimination Round World Cup Game So Far

SAM COLT
JUL 1, 2014, 7:33 PM
29,622 likes



NEWS HEADLINES

TOP STORIES

- TODAY I FEAT FIVE DAYS
- Machine Learning Set to Boost Search and Security
- Help Improve Windows Phone's Remote Desktop
- Chinese Game Maker Preps for Launch of Xbox One
- Cortana: Start Parties with World Cup Predictions
- All Updates for Windows, Internet Explorer Issues

REGISTER TODAY!

SNAPSHOT

Microsoft's Cortana Predicts World Cup Eliminations Correctly

Microsoft Bing's prediction technology is 13-0 in the World Cup knockout round

by Taylor Soper on 7/6/2014 at 2:53 pm | 4 Comments

World Cup football. Cortana, the artificial intelligence center of Microsoft's Bing Predicts, has correctly predicted the winner in 13 of 13 knockout round games.

Microsoft Bing's prediction engine was not impressive in the World Cup group stage, correctly picking 60 percent of the winning teams that advanced.

But its performance in the knockout round has been perfect — literally.

Bing is 13-0 thus far in the elimination stage of the World Cup.

Microsoft's Virtual Assistant Cortana Predicted Today's Blowout World Cup Game

Earlier we reported on how Cortana - Microsoft's virtual assistant for Windows Phones - had correctly predicted a series of World Cup games during the group stage.

But commenters weren't impressed by Cortana's accuracy.

Coupe du monde: Cortana, le prédict la victoire de l'Allemagne

Par L'EXPRESS.fr. publié le 03/07/2014 à 16:21. mis à jour à 16:28

Avec 8 pré concurrents, l'Allemagne

Microsoft's Cortana Has Predicted Every Elimination Round World Cup Game So Far

SAM COLT
JUL 1, 2014, 7:33 PM
29,622 likes

Microsoft's Cortana AI really predicted 12 World Cup games?

July 8, 2014 2:05 PM ET

Twitter/prince_aziz

Computational Thinking for Society

Archaeology

- eHeritage Project, Microsoft Research Asia
- Digital Forma Urbis Romae Project, Stanford
- Cathedral Saint Pierre, Columbia



- Crowd sourcing as a new way of getting news tips from sources
- Algorithmic approach to validate credibility of sources
- Digital Media and Learning Initiative, MacArthur Foundation

Journalism



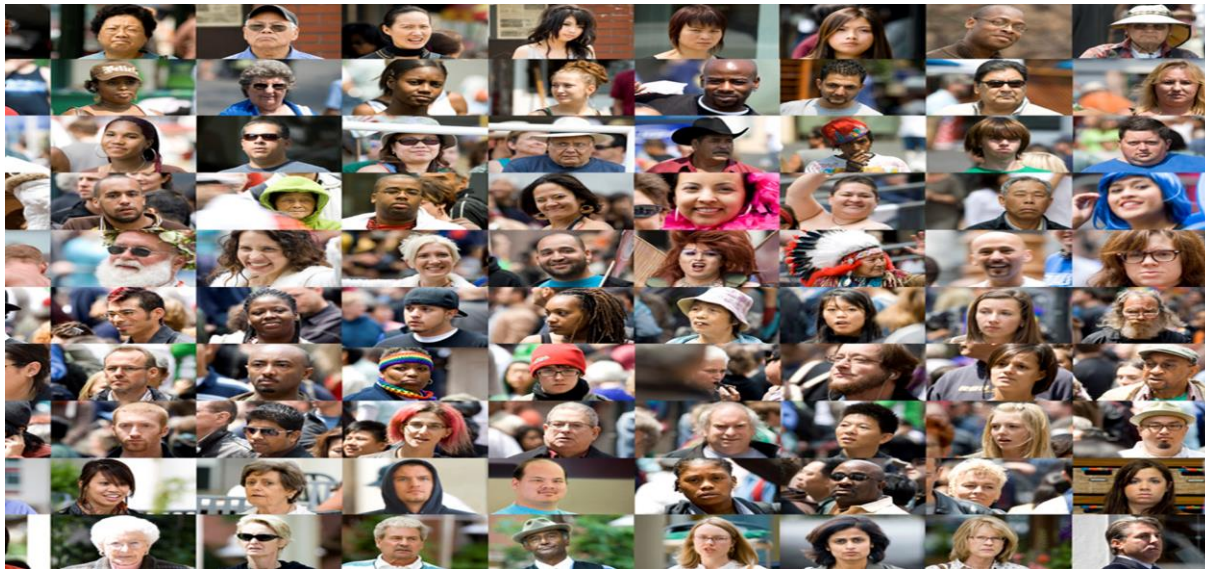
Humanities

- Digging into Data Challenge: What could you do with a million books?
Nat'l Endowment for the Humanities (US),
JISC (UK), SSHRC (Canada)
- Music, English, Art, Design, Photography, ...



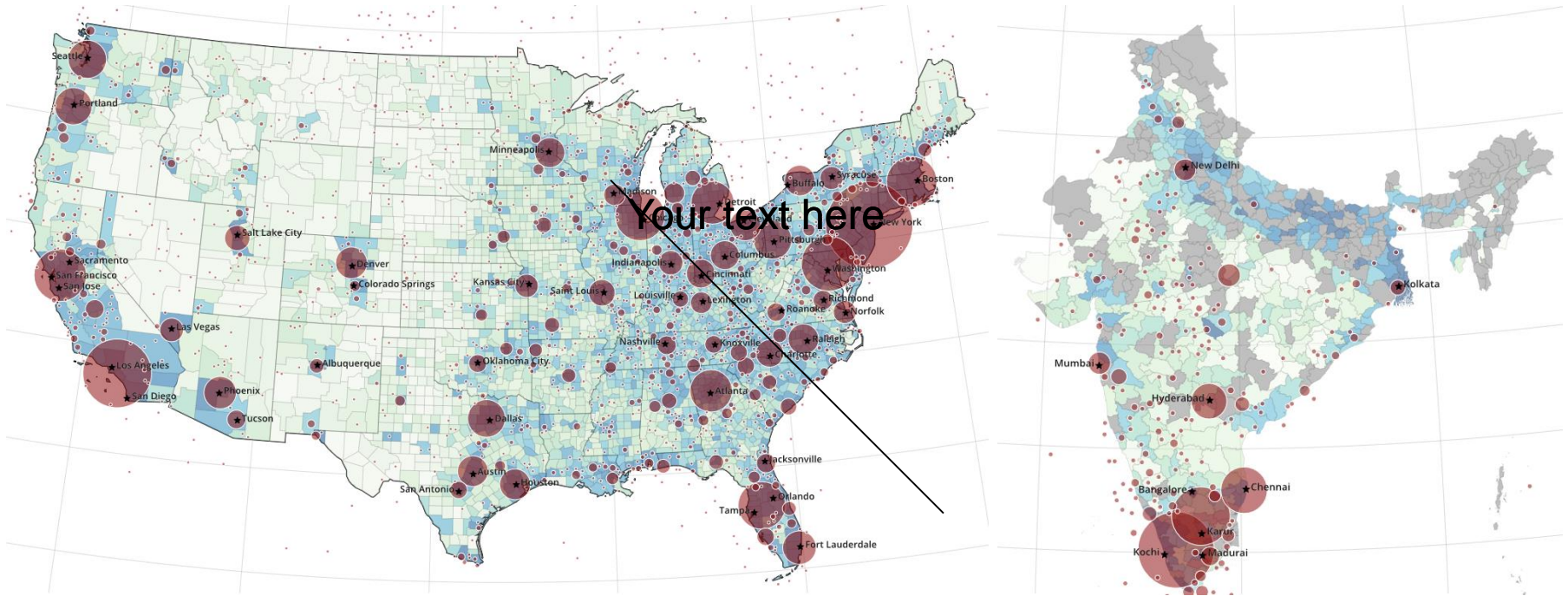
Computational Social Science: Learning about Crowdworkers

- Computational: digital studies **produce** the *nodes* (people) and *edges* (relationships) in a network



- Anthropology: qualitative studies **produce** the *variety of nodes* (individuals, institutions) and *meaning of edges* (motivations, hierarchies, power dynamics)

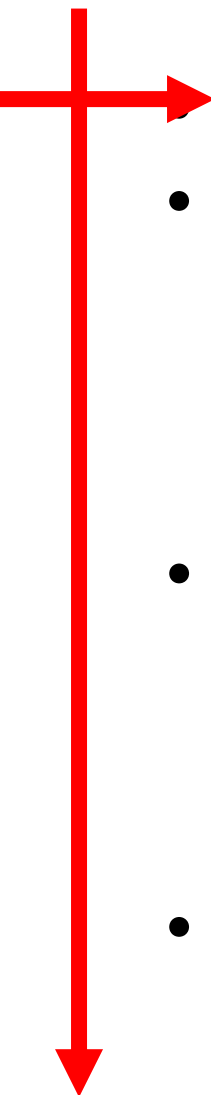
Mapping the Crowd



Self-reported locations for ~10,000 participants in a map task on Amazon Mechanical Turk. Coloration of counties/districts is by *population density*.

Computational Thinking in Education

Pre-K to Grey



→ K-6, 7-9, 10-12

- Undergraduate courses

- Freshmen year

- “Ways to Think Like a Computer Scientist” aka Principles of Computing

- Upper-level courses

- Graduate-level courses

- Computational arts and sciences

- E.g., entertainment technology, computational linguistics, ..., computational finance, ..., computational biology, computational astrophysics

- Post-graduate

- Executive and continuing education, senior citizens

- Teachers, not just students

Education Implications for K-12

Question and Challenge for the Computing Community:

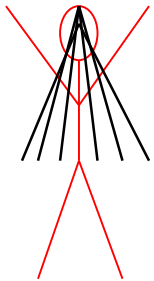
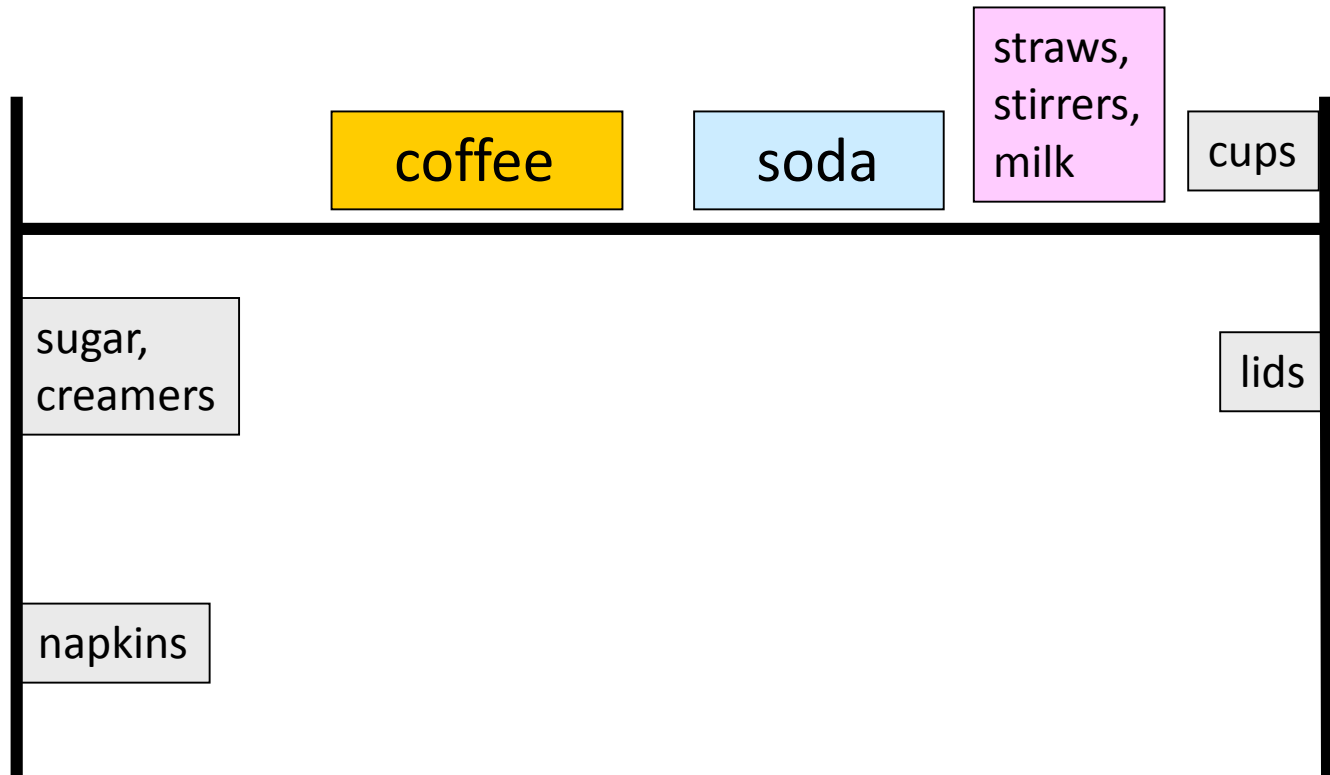
What is an effective way of learning (teaching) computational thinking by (to) K-12?

- What concepts can students (educators) best learn (teach) when?
What is our analogy to numbers in K, algebra in 7, and calculus in 12?
- We uniquely also should ask how best to integrate The Computer with teaching the concepts.

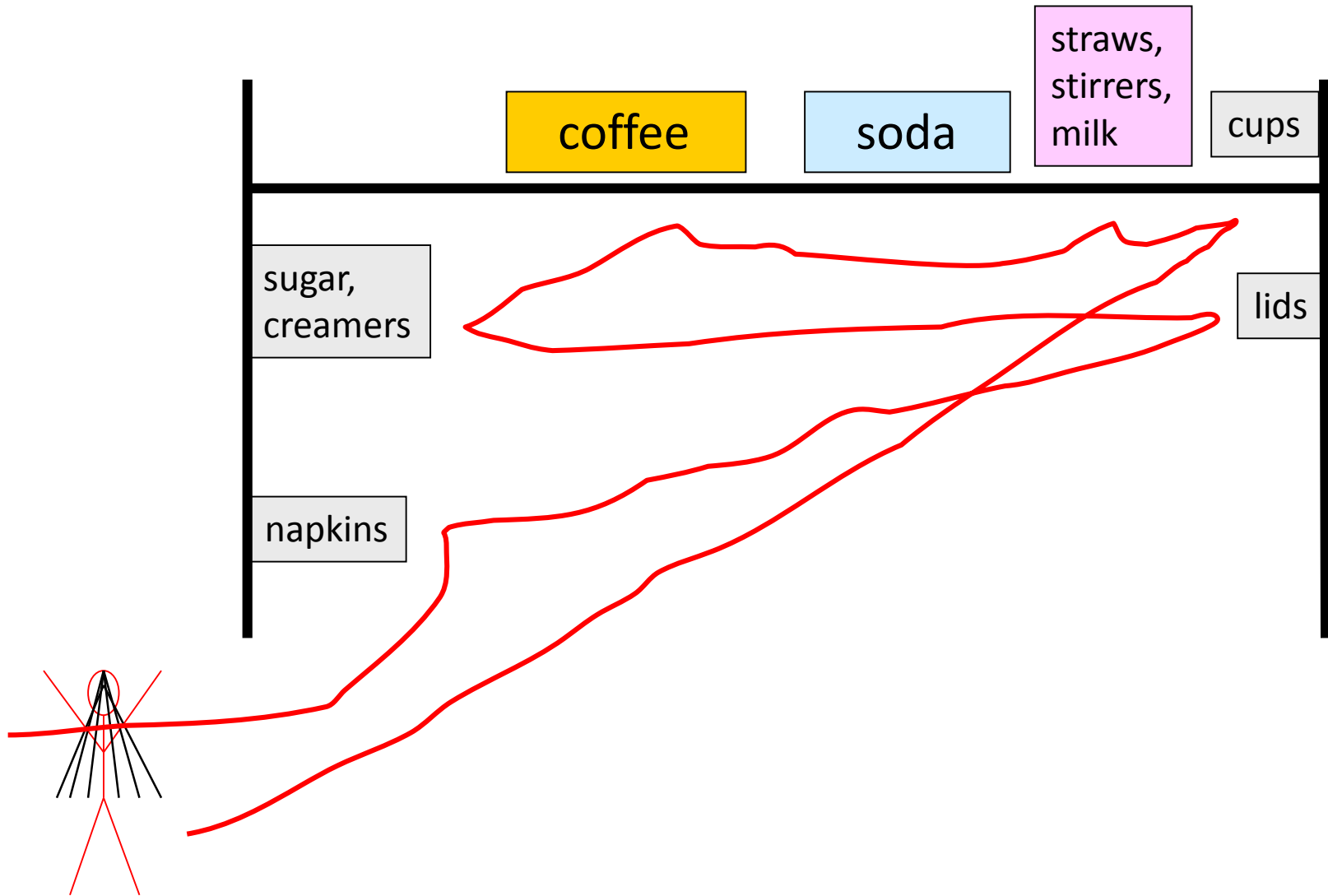
Computer scientists are now working with educators and cognitive learning scientists to address these questions.

Computational Thinking in Daily Life

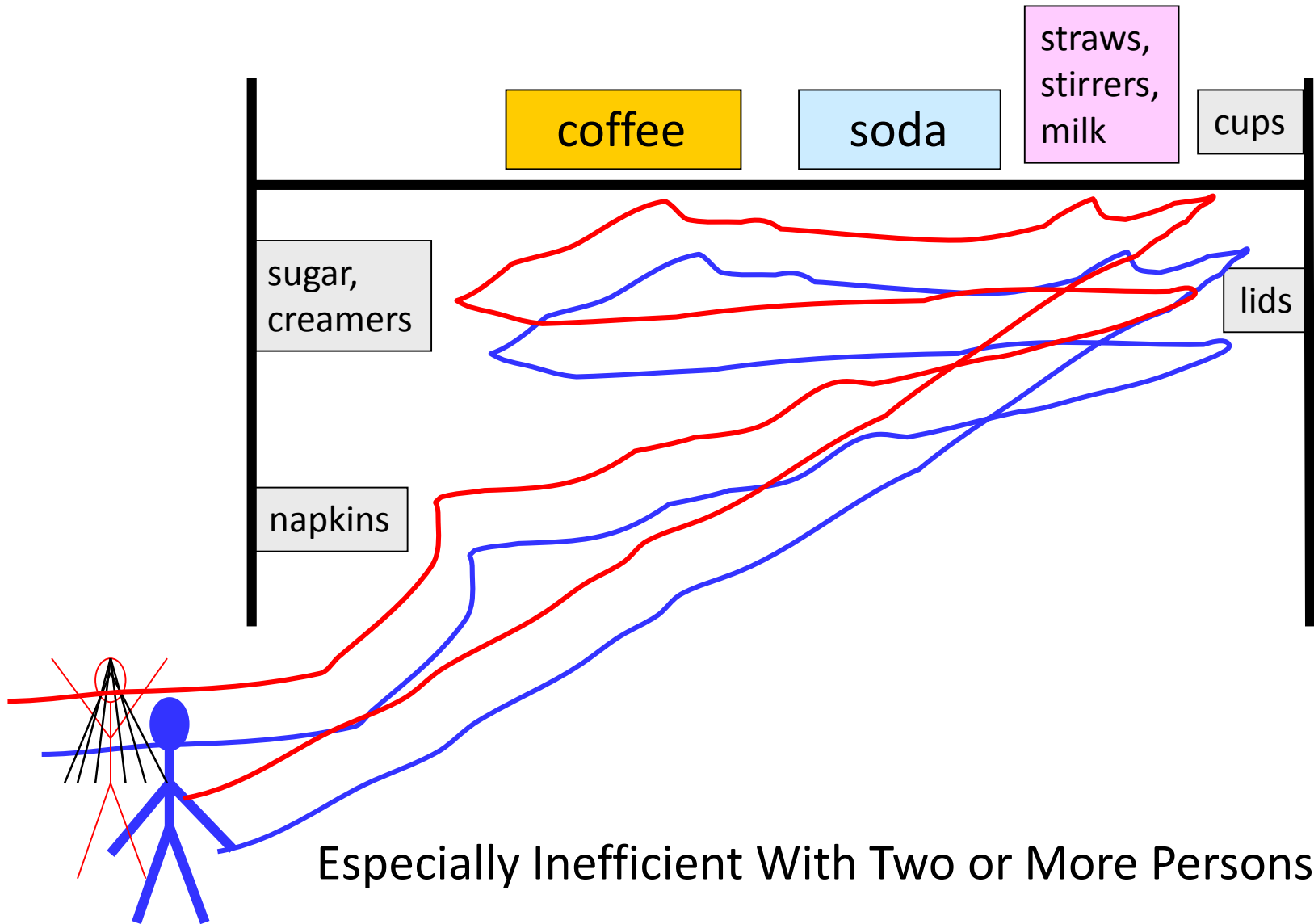
Getting Morning Coffee at the Cafeteria



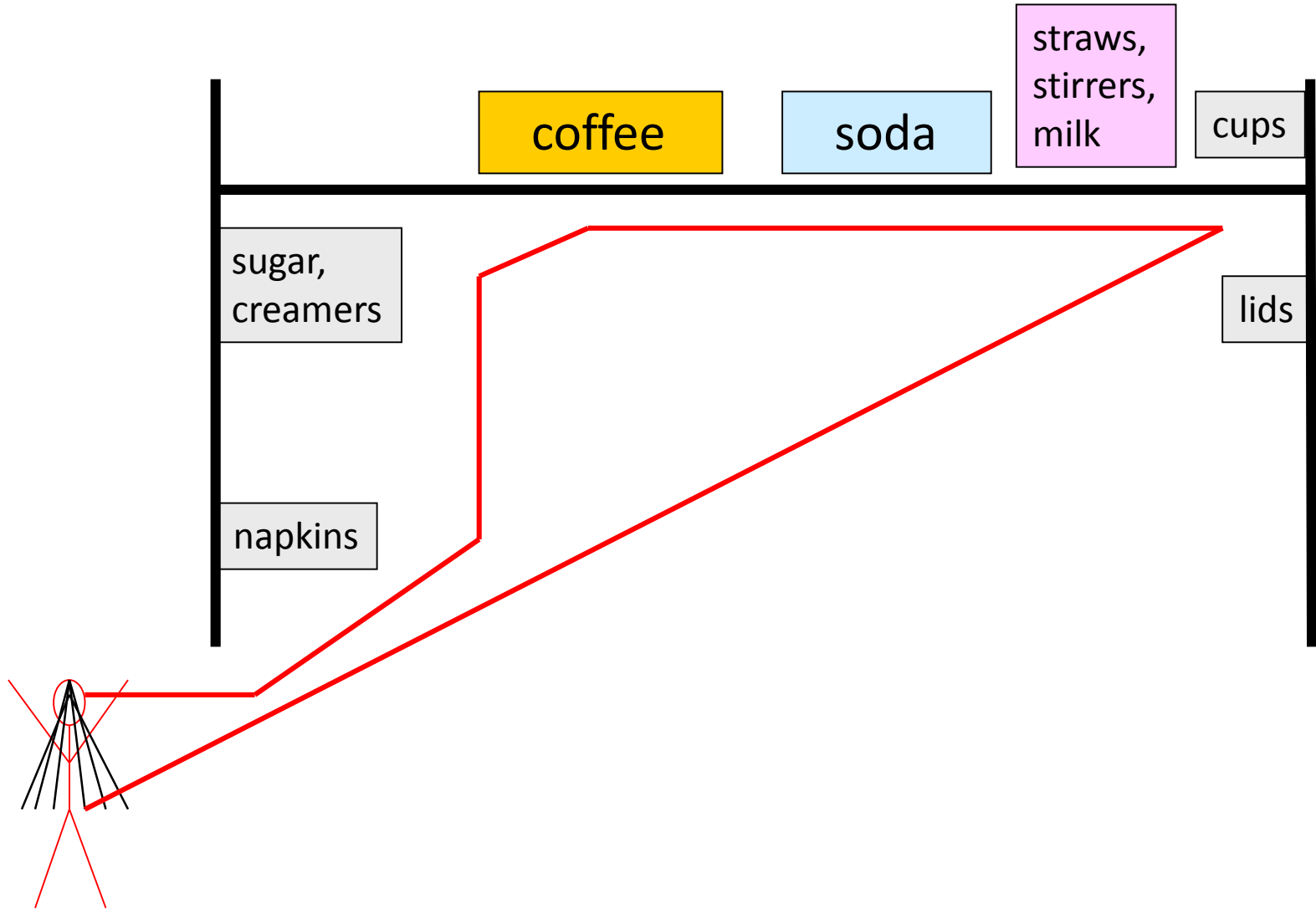
Getting Morning Coffee at the Cafeteria



Getting Morning Coffee at the Cafeteria



Better: Think Computationally—Pipelining!

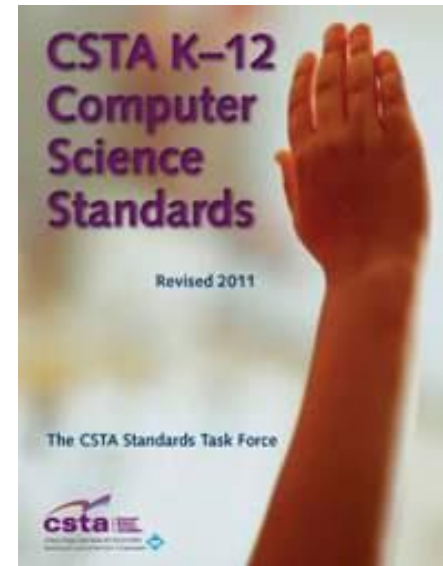


United States Efforts

High School



CS Principles: <http://csprinciples.org>
- With NSF support, revision of CS AP courses



K-12



<http://www.csta.acm.org/>

- *Computational Thinking Resource Set: A Problem-Solving Tool for Every Classroom*
- K-12 Computer Science Standards

CSTB Reports:

[The Report of a Workshop on Pedagogical Aspects of Computational Thinking](#) 2011

[Report of a Workshop on the Scope and Nature of Computational Thinking](#) 2010



Congress

Computer Science Education Act ([H.R.5929](#)) 2010

- proposed by PA Senator Casey and CO Representative Polis.



United Kingdom Efforts

British Royal Society (2012): *Shut down or restart? report*



“Computational thinking” offers insightful ways to view how information operates in many natural and engineered systems.

...

3. Every child should have the opportunity to learn Computing at school. We believe that:

- Every child should be expected to be ‘digitally literate’ by the end of compulsory education, in the same way that every child is expected to be able to read and write. “

Computing At School (K-12)

COMPUTING AT SCHOOL
EDUCATE · ENGAGE · ENCOURAGE
In collaboration with BCS, The Chartered Institute for IT

Establish computer science as a foundational subject discipline, like math or physics, that every child should learn, from primary school onwards.



An entirely new K-12 subject,
Computer Science,
started in England, Sept 2014.

International Efforts

Europe



Computational Thinking

Uniting Computer Science, Mathematics & Philosophy



NUI MAYNOOTH



Heidelberg Institute for Theoretical Studies



University of Zurich UZH



Asia

Computer Science (CS) Reloaded Programme

“...aims to deliver enrichment courses to pre-tertiary students to deepen their infocomm skills by supporting course fees for students to take up computer science courses anchored in **computational thinking**.”



COMMONCORE
The University of Hong Kong



毕业论文, 职称论文, 核心, EI论文发表 QQ:790062161

Computational thinking and computer fundamental education

Latin America

Investigación Información Innovación

- ▶ Buscadores
- ▶ Calendario
- ▶ Intranet
- ▶ Idiomas



Middle East

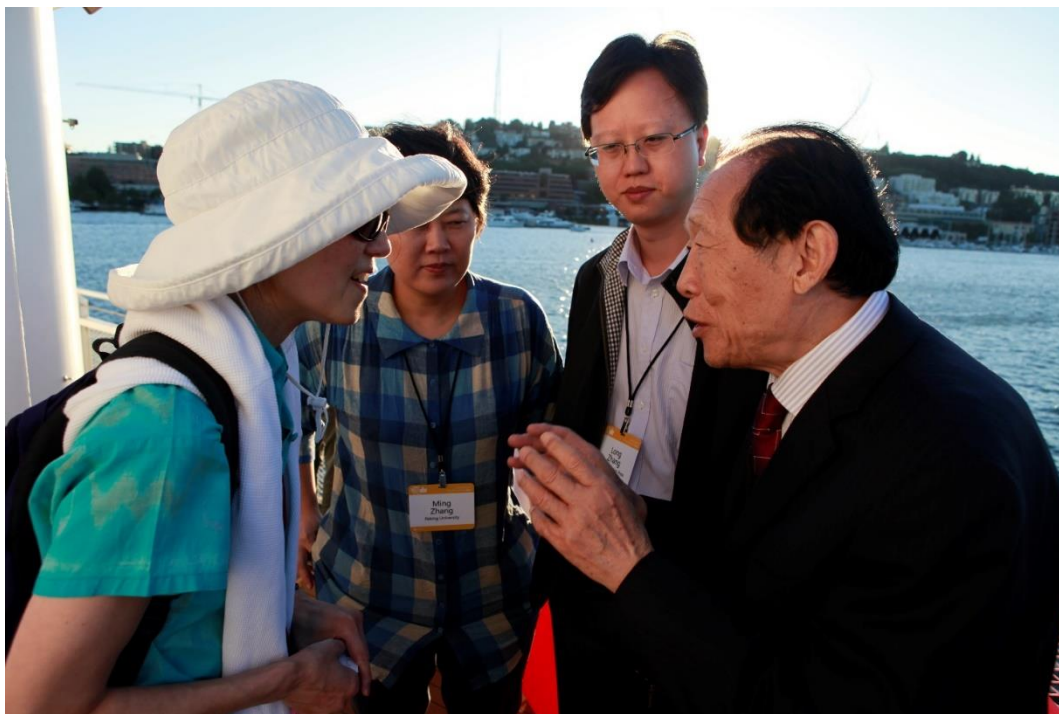
<http://ctegypt.blogspot.com/>

Computational Thinking in Egypt

Computational Thinking in China

Prof. Guoliang Chen (陈国梁院士) is one of the key influencers who put Computational Thinking as the core ability for CS Fundamental Courses in all China universities.

Prof. Guoliang Chen also started the first CS Fundamental Course of Computational Thinking.





中华人民共和国教育部

Ministry of Education of the People's Republic of China

- 政务之窗 | 机构设置 | 信息公开 | 新闻发布 | 公报公告 | 统计数据 | 政府采购 | 专题专栏 | 信息化 | 人事任免 | 政策法规 | 文献资料
- 服务大厅 | 行政审批 | 办事公开 | 项目指南 | 招生考试 | 就业指导 | 名单查询 | 学历查询 | 学历认证 | 学位查询 | 学位认证
- 互动平台 | 部长信箱 | 政策咨询 | 专家答疑 | 政策解读 | 征求意见 | 在线访谈 | 热线电话 | 滇西开发 | 移动客户端 | 新闻办微博 微信

【浏览字体：大 中 小】

关于公布2014年有关企业支持的校企合作 专业综合改革项目申报指南的通知


教高司函[2014]40号

- In 2012, The Chinese Ministry of Education (MOE) announced a program to reform Computing Fundamental Courses focusing on Computational Thinking.
- In 2014, MOE and Microsoft jointly put forward a new program to sponsor 16 full Computational Thinking Courses and 100 case studies.
- Empower 7 Million students with Computational Thinking ability through CS Fundamental Courses.

Computational Thinking, International

计算思维

周以真



计算思维代表着一种普遍的认识和一类普适的技能，每一个人，而不仅仅是计算机科学家，都应热心于它的学习和运用。

计算思维建立在计算过程的能力和限制之上，由人由机器执行。计算方法和模型使我们敢于去处
一步问：一个近似解是否就足够了，是否可以利用一下随机化、以及是否允许误报 (false)
In Bulletin of Specif, December 2008

La pensée informatique

par Jeannette M. Wing

Cet article fait suite aux divers interviews que nous avons faits et qui nous invitaient à une réflexion sur les fondements de notre discipline et ses aspects philosophiques et épistémologiques. Aujourd'hui l'article de Jeannette Wing nous conduit à réfléchir sur l'utilité et l'ubiquité de la pensée informatique et ses implications, mais aussi sur l'essence même de cette pensée.

Spread the Word

- Help make computational thinking commonplace!

To fellow faculty, students, researchers, administrators,
teachers, parents, principals, guidance counselors, school
boards, teachers' unions,
congressmen, policy makers, ...

Thank you!

References (Representative Only)

- Computational Thinking
 - University of Edinburgh, <http://www.inf.ed.ac.uk/research/programmes/comp-think/>
 - [Wing06] J.M. Wing, “Computational Thinking,” *CACM Viewpoint*, March 2006, pp. 33-35, <http://www.cs.cmu.edu/~wing/>
- Model Checking, Temporal Logic, Binary Decisions Diagrams
 - [Br86] Randal Bryant, “Graph-Based Algorithms for Boolean Function Manipulation,” *IEEE Trans. Computers*, 35(8): 677-691 (1986).
 - [CE81] E. M. Clarke and E. A. Emerson, “The Design and Synthesis of Synchronization Skeletons Using Temporal Logic,” *Proceedings of the Workshop on Logics of Programs*, IBM Watson Research Center, Yorktown Heights, New York, Springer-Verlag Lecture Notes in Computer Science, #131, pp. 52–71, May 1981.
 - [CES86] E. M. Clarke, E. A. Emerson, and A. P. Sistla, “Automatic Verification of Finite State Concurrent Systems Using Temporal Logic Specifications,” *ACM Trans. Prog. Lang. and Sys.*, (8)2, pp. 244-263, 1986.
 - [CGP99] Edmund M. Clarke, Jr., Orna Grumberg and Doron A. Peled, *Model Checking*, MIT Press, 1999, ISBN 0-262-03270-8.
 - [Ku94] Robert P. Kurshan, *Computer Aided Verification of Coordinating Processes: An Automata-theoretic Approach*, Princeton Univ. Press, 1994.
 - [Pn77] Amir Pnueli, “The Temporal Logic of Programs,” *Foundations of Computer Science*, FOCS, pp. 46-57, 1977.
 - [QS82] Jean-Pierre Queille, Joseph Sifakis, “Specification and verification of concurrent systems in CESAR,” *Symposium on Programming*, Springer LNCS #137 1982: 337-351.
 - [VW86] Moshe Y. Vardi and Pierre Wolper, “An Automata-Theoretic Approach to Automatic Program Verification (Preliminary Report),” *Logic in Computer Science*, LICS 1986: 332-344.
- Computational Thinking and Biology
 - [Model Checking of a Diabetes-Cancer Model](#). H. Gong, P. Zuliani, E. M. Clarke. In CMLS 2011: 3rd International Symposium on Computational Models for Life Sciences, AIP Conf. Proc. 1371, pages 234-243, 2011.
 - [Symbolic Model Checking of Signaling Pathways in Pancreatic Cancer](#). H. Gong, Q. Wang, P. Zuliani, J. R. Faeder, M. T. Lotze, E. M. Clarke. In BiCoB 2011: 3rd International Conference on Bioinformatics and Computational Biology, March 23-25, 2011, New Orleans, LA.
 - [From Cardiac Cells to Genetic Regulatory Networks](#). R. Grosu, G. Batt, F. H. Fenton, J. Glimm, C. Le Guernic, S. A. Smolka, E. Bartocci. In CAV 2011: Proceedings of the 23rd International Conference on Computer-Aided Verification, LNCS 6806, pp. 396-411, 2011.
 - E. Bartocci, F. Corradini, M.R. Di Berardini et al. (2009) [Modeling and simulation of cardiac tissue using hybrid I/O automata](#)☆, 3149-3165. In *Theoretical Computer Science* 410 (33-34). <http://dblp.uni-trier.de/db/journals/...>
 - Radu Grosu, Scott A. Smolka, Flavio Corradini et al. (2009) [Learning and detecting emergent behavior in networks of cardiac myocytes](#), 97. In *Communications of the ACM* 52 (3). <http://dblp.uni-trier.de/db/journals/...>
 - Allesina and Pascual, “Googling Food Webs: Can an Eigenvector Measure Species' Importance for Coextinctions?”, *PLoS Computational Biology*, 5(9), September 4, 2009. <http://www.ploscompbiol.org/article/info:doi%2F10.1371%2Fjournal.pcbi.1000494>
 - Executable Cell Biology, Jasmin Fisher and Thomas A Henzinger, *Nature Biotechnology*, Vol. 25, No. 11, November 2007. (See paper for many other excellent references.)
 - [LJ07] Predicting Protein Folding Kinetics via Temporal Logic Model Checking, Christopher Langmead and Sumit Jha, WABI, 2007.
 - Systems Biology Group, Ziv Bar-Joseph, Carnegie Mellon University, <http://www.sb.cs.cmu.edu/pages/publications.html>

References (Representative Only)

- Machine Learning and Applications
 - Christopher Bishop, *Pattern Recognition and Machine Learning*, Springer, 2006.
 - [FS99] Yoav Freund and Robert E. Schapire, “A short introduction to boosting.” *Journal of Japanese Society for Artificial Intelligence*, 14(5):771-780, September, 1999.
 - Tom Mitchell, *Machine Learning*, McGraw Hill, 1997
 - Symbolic Aggregate Approximation, Eamonn Keogh, UC Riverside, <http://www.cs.ucr.edu/~eamonn/SAX.htm> (applications in Medical, Meteorological and many other domains)
 - The Auton Lab, Artur Dubrawski, Jeff Schneider, Andrew Moore, Carnegie Mellon, <http://www.autonlab.org/autonweb/2.html> (applications in Astronomy, Finance, Forensics, Medical and many other domains)
- Computational Thinking and Astronomy
 - J. Gray, A.S. Szalay, A. Thakar, P. Kunszt, C. Stoughton, D. Slutz, J. vandenBerg, “Data Mining the SDSS SkyServer Database,” in *Distributed Data & Structures 4: Records of the 4th International Meeting*, W. Litwin, G. Levy (eds), Paris France March 2002, Carleton Scientific 2003, ISBN 1-894145-13-5, pp 189-210.
 - Sloan Digital Sky Survey @Johns Hopkins University, <http://www.sdss.jhu.edu/>
- Computational Thinking and Archaeology
 - Columbia University: <http://www.cs.columbia.edu/~atroccol/>
 - Digital Forma Urbis Romae Project: <http://www.graphics.stanford.edu/projects/forma-urbis/>
 - eHeritage Project, MSRA: <http://research.microsoft.com/en-us/collaboration/global/asia-pacific/programs/eheritage.aspx>
 - See also Marc Levoy’s digital archaeology projects: <http://www-graphics.stanford.edu/~levoy/>
 - See also UK universities: http://en.wikipedia.org/wiki/Computational_archaeology#Research_groups_and_institutions
- Computational Thinking and Chemistry
 - [Ma07] Paul Madden, Computation and Computational Thinking in Chemistry, February 28, 2007 talk off <http://www.inf.ed.ac.uk/research/programmes/comp-think/previous.html>
- Computational Thinking and Economics
 - Abraham, D., Blum, A. and Sandholm, T., “Clearing algorithms for barter exchange markets: enabling nationwide kidney exchanges,” *Proc. 8th ACM Conf. on Electronic Commerce*, pp. 295–304. New York, NY: Association for Computing Machinery, 2007.
 - Conitzer, V., Sandholm, T., and Lang, J., [When Are Elections with Few Candidates Hard to Manipulate?](#) *Journal of the ACM*, 54(3), June 2007.

References (Representative Only)

- Conitzer, V. and Sandholm, T., [Universal Voting Protocol Tweaks to Make Manipulation Hard](#). In Proceedings of the *International Joint Conference on Artificial Intelligence (IJCAI)*, 2003.
- Michael Kearns, Computational Game Theory, Economics, and Multi-Agent Systems, University of Pennsylvania, <http://www.cis.upenn.edu/~mkearns/#gamepapers>
- Algorithmic Game Theory, edited by Noam Nisan, Tim Roughgarden, Eva Tardos, and Vijay V. Vazirani, September 2007, <http://www.cambridge.org/us/catalogue/catalogue.asp?isbn=9780521872829>
- David Pennock, Yahoo! Research, Algorithmic Economics, http://research.yahoo.com/ksc/Algorithmic_Economics
- Computational Thinking and Journalism
 - MacArthur Foundation Digital Media and Learning Initiative: http://www.macfound.org/site/c.1kLXJ8MQKrH/b.946881/k.B85/Domestic_Grantmaking_Digital_Media_Learning.htm
 - Kim Pearson, Poynter Online, eMedia Tidbits, May 2009: <http://www.poynter.org/column.asp?id=31&aid=164084>
 - Georgia Tech: <http://www.computation-and-journalism.com/main/>
- Computational Thinking and Law
 - The Poirot Project, <http://www.ffpoirot.org/>
 - Robert Plotkin, Esq., *The Genie in the Machine: How Computer-Automated Inventing is Revolutionizing Law and Business*, forthcoming from Stanford University Press, April 2009, Available from www.geniemachine.com
 - Burkhard Schafer, Computational Legal Theory, http://www.law.ed.ac.uk/staff/burkhardschafer_69.aspx
 - Stanford Computational Law, <http://complaw.stanford.edu/>
- Computational Thinking and Medicine and Healthcare
 - The Diamond Project, Intel Research Pittsburgh, <http://techresearch.intel.com/articles/Tera-Scale/1496.htm>
 - Institute for Computational Medicine, Johns Hopkins University, <http://www.icm.jhu.edu/>
 - See also Symbolic Aggregate Approximation, Eamonn Keogh, UC Riverside, <http://www.cs.ucr.edu/~eamonn/SAX.htm>
 - SM Belknap, H Moore, SA Lanzotti, PR Yarnold, M Getz, DL Deitrick, A Peterson, J Akeson, T Maurer , RC Soltysik, GA Storm, and I Brooks, Application of Software Design Principles and Debugging Methods to an Analgesia Prescription Reduces Risk of Severe Injury From Medical Use of Opioids, *Clinical pharmacology & Therapeutics*, Vol 84 No. 3 , September 2008, pp. 385-392.
- Computational Thinking and Meteorology
 - Yubin Yang, Hui Lin, Zhongyang Guo, Jixi Jiang, “A data mining approach for heavy rainfall forecasting based on satellite image sequence analysisSource,” *Computers and Geosciences*, Volume 33 , Issue 1, January 2007, pp. 20-30, ISSN:0098-3004.
 - See also Symbolic Aggregate Approximation, Eamonn Keogh, UC Riverside, <http://www.cs.ucr.edu/~eamonn/SAX.htm>

References (Representative Only)

- Computational Thinking (especially Machine Learning) and Neuroscience
 - Yong Fan, Dinggang Shen, Davatzikos, C., “**Detecting Cognitive States from fMRI Images by Machine Learning and Multivariate Classification,**” Computer Vision and Pattern Recognition Workshop, 2006. CVPRW '06, June 2006, p. 89.
 - T.M. Mitchell, R. Hutchinson, R.S. Niculescu, F.Pereira, X. Wang, M. Just, and S. Newman, "[Learning to Decode Cognitive States from Brain Images](#),"*Machine Learning*, Vol. 57, Issue 1-2, pp. 145-175. October 2004.
 - X. Wang, R. Hutchinson, and T. M. Mitchell, "[Training fMRI Classifiers to Detect Cognitive States across Multiple Human Subjects](#)," *Neural Information Processing Systems 2003*. December 2003.
 - T. Mitchell, R. Hutchinson, M. Just, R.S. Niculescu, F. Pereira, X. Wang, "[Classifying Instantaneous Cognitive States from fMRI Data](#)," *American Medical Informatics Association Symposium*, October 2003.
 - Dmitri Samaras, Image Analysis Lab, <http://www.cs.sunysb.edu/~ial/brain.html>
 - Singh, Vishwajeet and Miyapuram, K. P. and Bapi, Raju S., “*Detection of Cognitive States from fMRI data using Machine Learning Techniques,*” *IJCAI, 2007*.
- Computational Thinking and Sports
 - Synergy Sports analyzes NBA videos, <http://broadcastengineering.com/news/video-data-dissect-basketball-0608/>
 - Lance Armstrong’s cycling computer tracks man and machine statistics, website

Credits

- Copyrighted material used under Fair Use. If you are the copyright holder and believe your material has been used unfairly, or if you have any suggestions, feedback, or support, please contact: jsoleil@nsf.gov
- Except where otherwise indicated, permission is granted to copy, distribute, and/or modify all images in this document under the terms of the GNU Free Documentation license, Version 1.2 or any later version published by the Free Software Foundation; with no Invariant Sections, no Front-Cover Texts, and no Back-Cover Texts. A copy of the license is included in the section entitled “GNU Free Documentation license”
(http://commons.wikimedia.org/wiki/Commons:GNU_Free_Documentation_License)