



Microsoft
Research Silicon Valley

Reimagining Textbooks Through the Data Lens

Rakesh Agrawal

Microsoft Research – Silicon Valley

Joint work with S. Gollapudi, A. Kannan, & K. Kenthapadi

February 15, 2013

Thesis



Education generally, and cloud-connected electronic books particularly, provide huge opportunity to expand and grow data mining research

Outline



- Importance of electronic textbooks
- Enriching textbooks through data mining
- Research opportunities
- Concluding thoughts

Outline



- Importance of electronic textbooks
- Enriching textbooks through data mining
- Research opportunities
- Concluding thoughts

Three Trends

- Centrality of good educational material for economic development
- Continued Increased adoption of Internet
- Emergence of tablets/e-readers

Education and Textbooks



Education: Primary vehicle for improving economic well-being of people

– *World Bank Reports, 1998, 2007*

Textbooks: Most cost-effective means of positively impacting educational quality

– Also indispensable for fostering teacher learning and for their ongoing professional development

– *Works by Clarke, Crossley, Fuller, Hanushek, Lockheed, Murby, Vail, and others*



2.3B Global Internet Users in 2011* – 8% Growth*, Driven by Emerging Markets

Rank	Country	2008-2011 Internet User Adds (MMs)	2011 Internet Users (MMs)	Y/Y Growth	Population Penetration
1	China	215	513	12%	38%
2	India	69	121	38	10
3	Indonesia	37	55	22	23
4	Philippines	28	34	44	35
5	Nigeria	21	45	--*	28
6	Mexico	19	42	19	37
7	Russia	16	61	3	43
8	USA	15	245	1	79
9	Iran	14	37	--*	48
10	Turkey	11	36	26	49
	Top 10	444	1,189	12%	32%
	World	663	2,250	8%	32%

Growth in Tablets/e-Readers:

29% US adult owners from 2% in less than 3 years

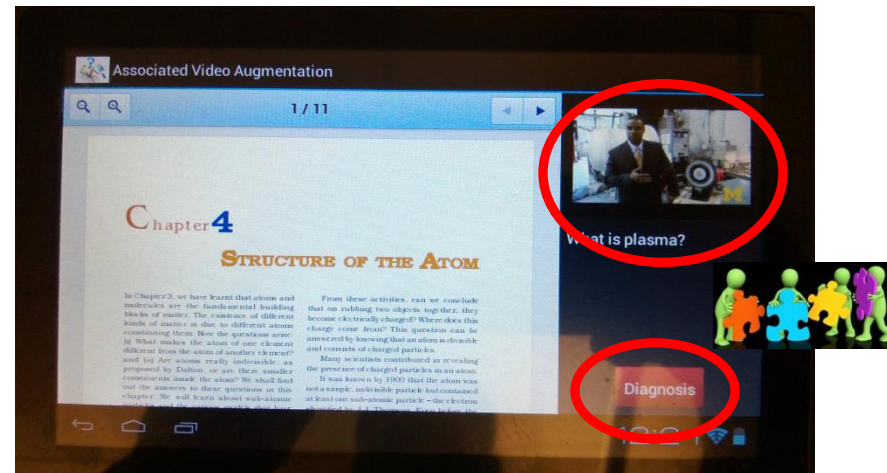
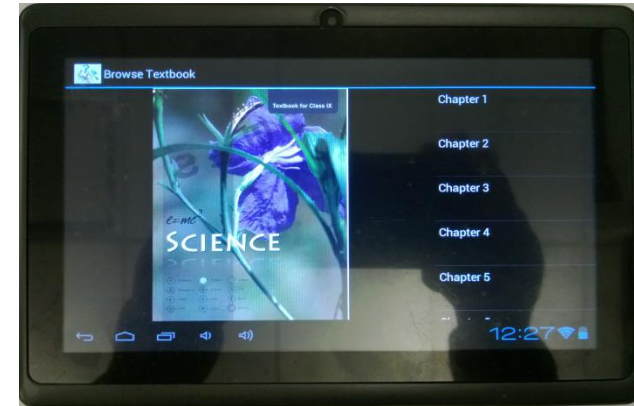
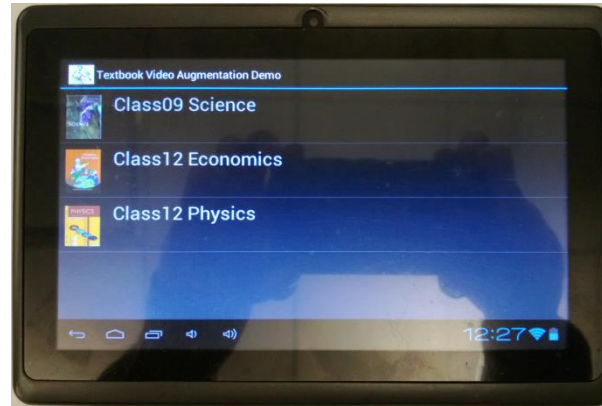


President Pranab Mukherjee unveils Rs. 1,130 Aakash 2 tablet

Agence France-Presse, November 12, 2012

Source: Pew Research Center, 1/12.

Reimagining Textbooks



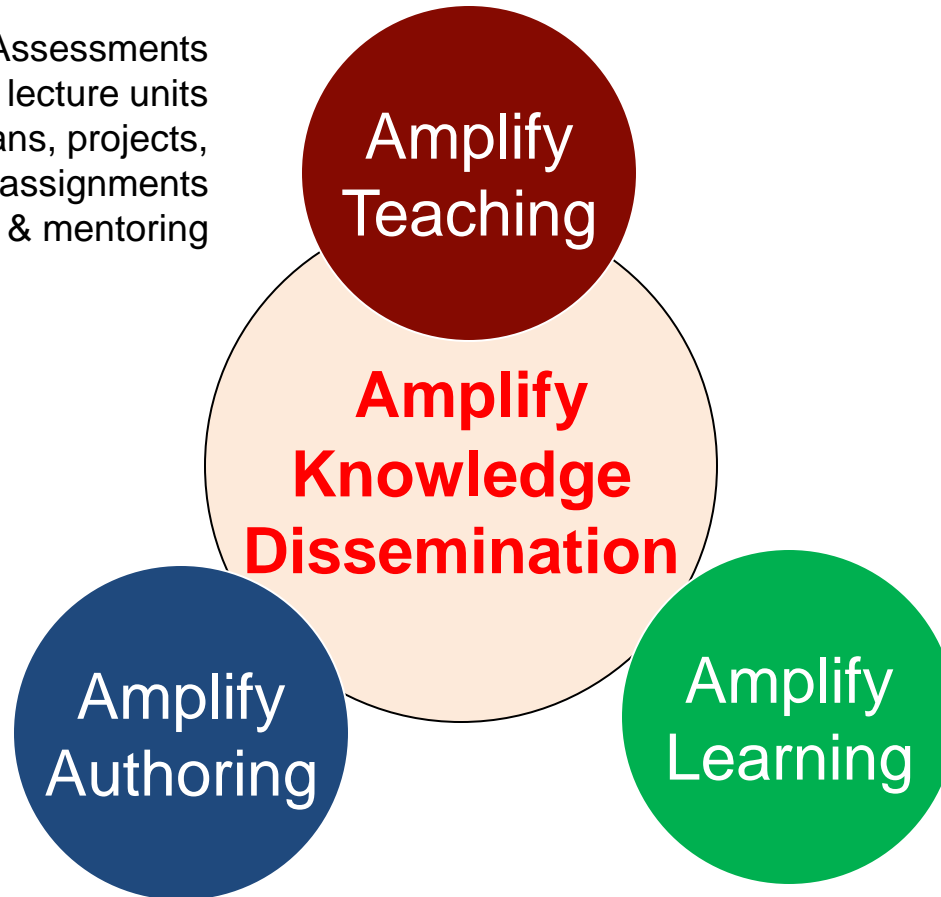
Outline



- Importance of electronic textbooks
- Enriching textbooks through data mining
- Research opportunities
- Concluding thoughts

Project Knowledge Amplifier (Ka)

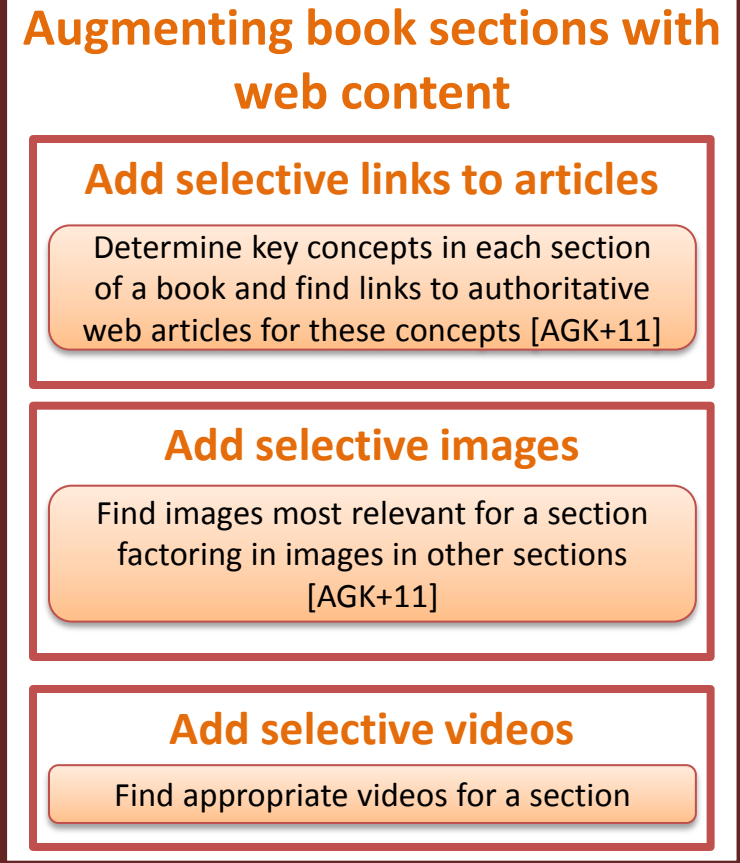
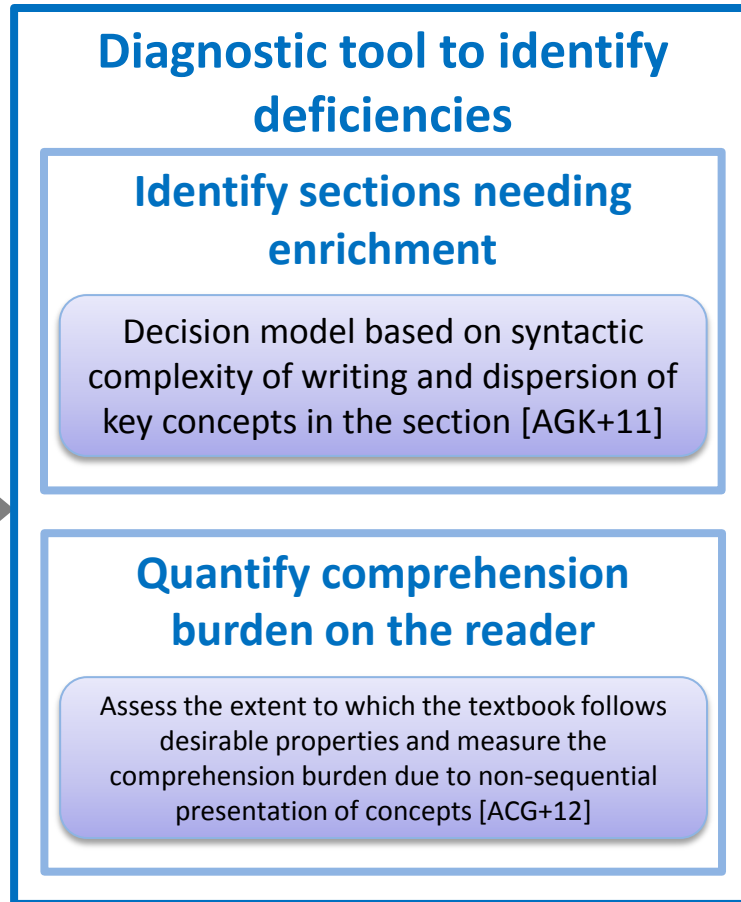
- Automated Assessments
- Identification of lecture units
 - Teaching plans, projects, assignments
- WW Collaboration & mentoring



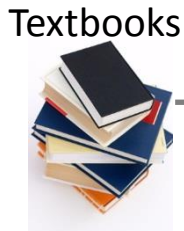
- Intra² & Inter⁴ section deficiency diagnosis
- Authoring by outlining

- Textbook augmentation^{1,3,5}
- Study Navigator⁶
- WW study groups⁷
- Progress indicators
- Appropriateness
- Interaction mining

Data Mining for Enriching Textbooks

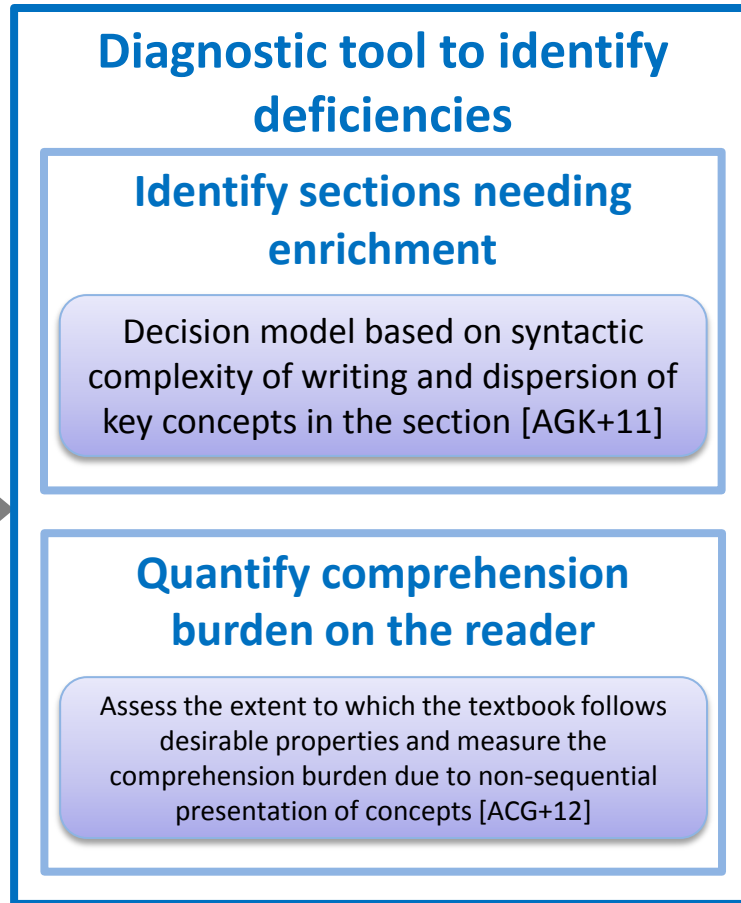


Vetted on high school textbooks (NCERT, India): Grades IX – XII
Across subjects



[AGK+11] [Data Mining for improving Textbooks](#), SIGKDD Explorations, 13(2), 2011 (summary of 3 earlier papers).
[ACG+12] [Empowering Authors to Diagnose Comprehension Burden in Textbooks](#), KDD 2012.

Data Mining for Enriching Textbooks



Augmenting book sections with web content

Add selective links to articles

Determine key concepts in each section of a book and find links to authoritative web articles for these concepts [AGK+11]

Add selective images

Find images most relevant for a section factoring in images in other sections [AGK+11]

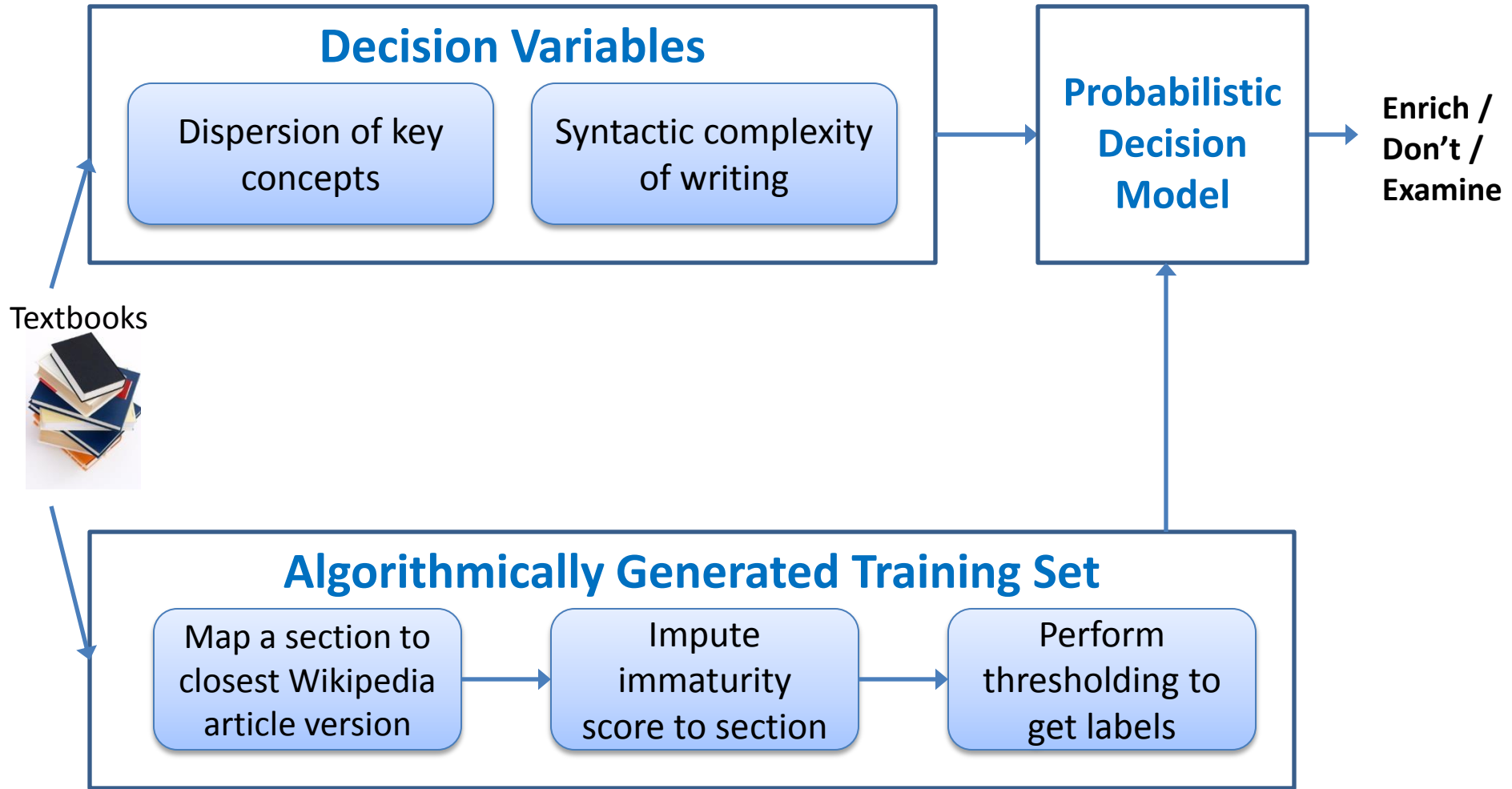
Add selective videos

Find appropriate videos for a section

Vetted on high school textbooks (NCERT, India): Grades IX – XII
Across subjects

[AGK+11] [Data Mining for improving Textbooks](#), SIGKDD Explorations, 13(2), 2011 (summary of 3 earlier papers).
[ACG+12] [Empowering Authors to Diagnose Comprehension Burden in Textbooks](#), KDD 2012.

Sections Needing Enrichment

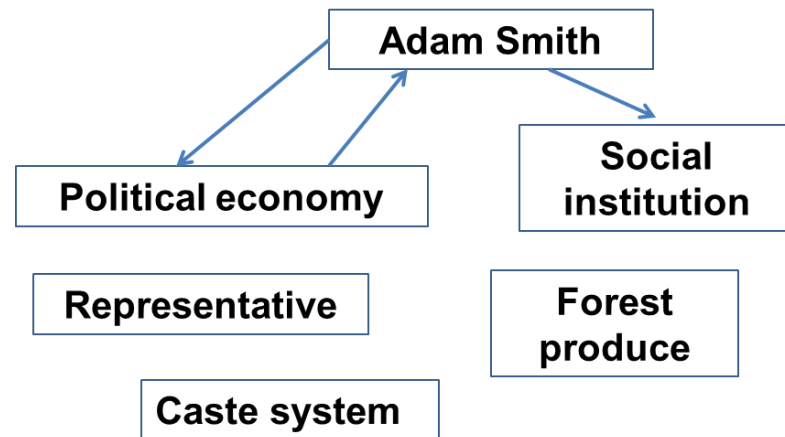
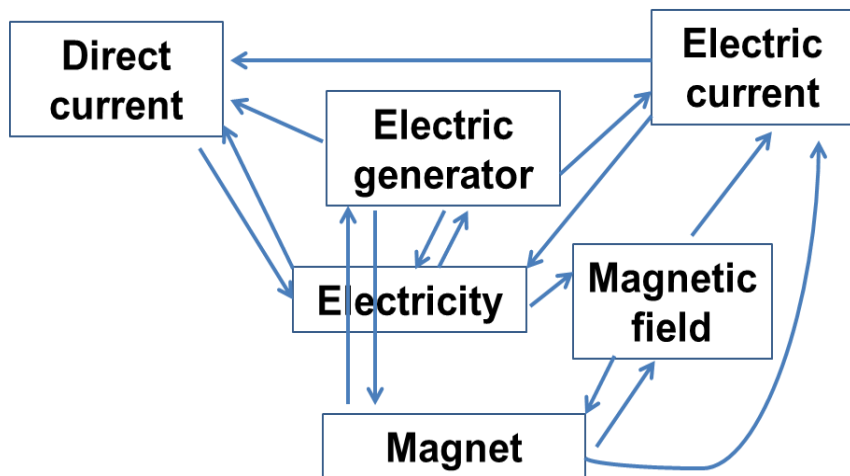
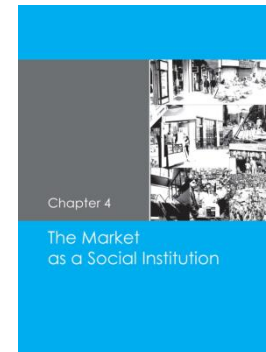
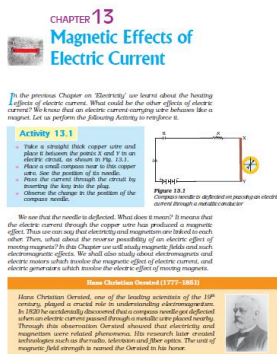


Decision Variables

Dispersion of key concepts

Syntactic complexity of writing

Many unrelated concepts in a section → Hard to understand section



Computing Dispersion

- V = set of key concepts discussed in section s
 - *Terminological noun phrases*: Linguistic pattern A^*N^+ (A: adjective; N: noun)
 - “*concepti*” Wikipedia titles
- $Related(x,y)$ = Concept x is related to concept y
 - *Co-occurrence*
 - *true* if Wikipedia article for x links to the article for y
- $Dispersion(s)$:= Fraction of unrelated concept pairs
 - $(1 - \text{Edge Density})$ of the concept graph

CHAPTER 13
Magnetic Effects of
Electric Current

In the previous Chapter on "Electricity" we learnt about the heating effect of electric current. What could be the other effects of electric current? We know that an electric current carrying wire behaves like a magnet. Let us perform the following activity to verify this.

Activity 13.1

- Take a straight thick copper wire and place it between the poles of a DC electric circuit, as shown in Fig. 13.1.
- Place a small compass near to the copper wire, over the portion of its length.
- Pass the current through the circuit by pushing the key into the plug.
- Observe the deflection in the position of the compass needle.

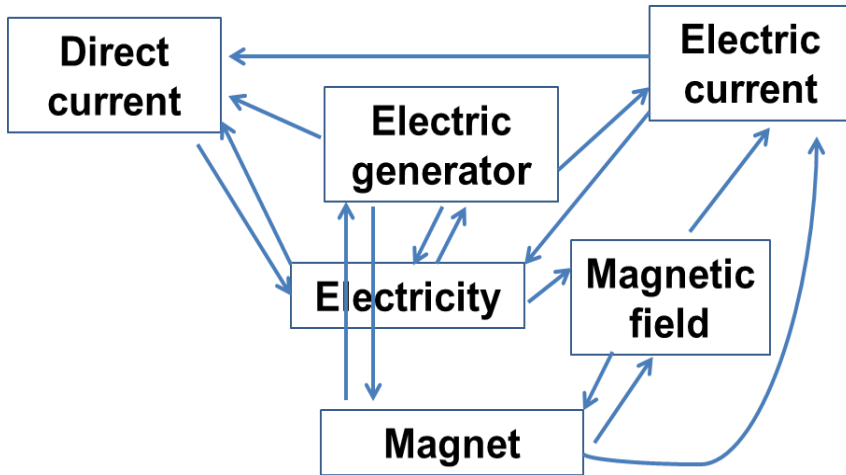
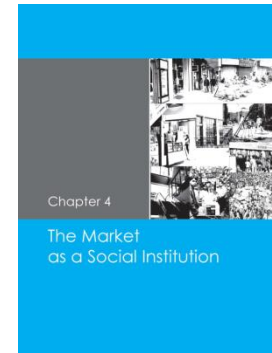


Figure 13.1
Current makes a deflection in position of electric current through a metal conductor.

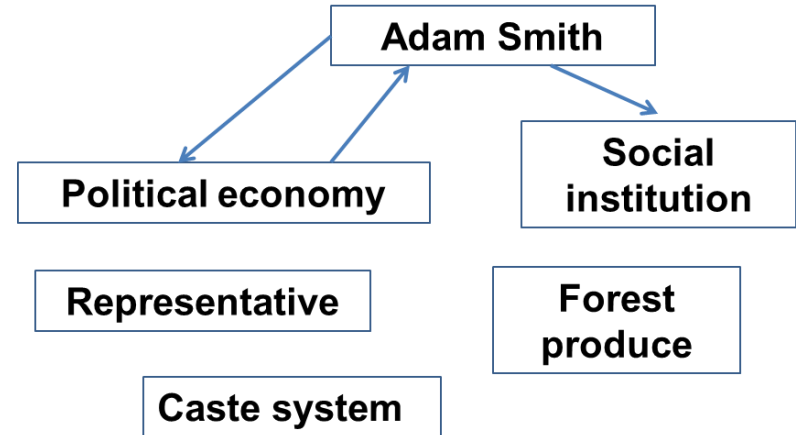
We would like to recall that, when a current is passed through the copper wire, it produces a magnetic effect. This current may have deflected the compass needle towards either side. What about the reverse possibility of an electric effect of moving magnets? In this Chapter we will study magnetic fields and study electromagnetic effects. We shall also study about electromagnets and electric motors which involve the magnetic effect of electric current, and electric generators which involve the electric effect of moving magnets.

From *Classroom Discussion (13.1)*
Have Oersted observed one of the leading scientists of the 19th century, played a crucial role in understanding electromagnetism. In 1820 he accidentally discovered that a compass needle got deflected when an electric current passed through a nearby wire placed nearby. Through this observation Oersted showed that electricity and magnetism were related phenomena. His research later created technologies such as telegraphs, telephones and other devices. The unit of magnetic field strength is named the Oersted in his honour.

Many unrelated concepts in a section → Hard to understand section



Dispersion = $1 - 15/30 = 0.5$



Dispersion = $1 - 3/30 = 0.9$

Larger dispersion → greater need for augmentation

Decision Variables

Dispersion of key concepts

Syntactic complexity of writing

- 100+ years of readability research
- 200+ Readability formulas
 - In widespread use (notwithstanding limitations)
- Popular formulas:

Flesch Reading Ease Score [17]	206.835	–	84.6	×	S/W	–	1.015	×	W/T
Flesch-Kincaid Grade Level [31]	–15.59	+	11.8	×	S/W	+	0.39	×	W/T
Dale-Chall Grade Level [14]	14.862	–	11.42	×	D/W	+	0.0512	×	W/T
Gunning Fog Index [23]			40	×	C/W	+	0.4	×	W/T
SMOG Index [37]	3.0	+	$\sqrt{30}$	×	$\sqrt{C/T}$				
Coleman-Liau Index [10]	–15.8	+	5.88	×	L/W	–	29.59	×	T/W
Automated Readability Index [46]	–21.43	+	4.71	×	L/W	+	0.50	×	W/T

C	=	Number of words with three syllables or more
D	=	Number of words on the Dale Long List
L	=	Number of letters
S	=	Number of syllables
T	=	Number of sentences
W	=	Number of words

- Regression coefficients learned over specific datasets
 - McCall-Crabbs Standard Test Lessons

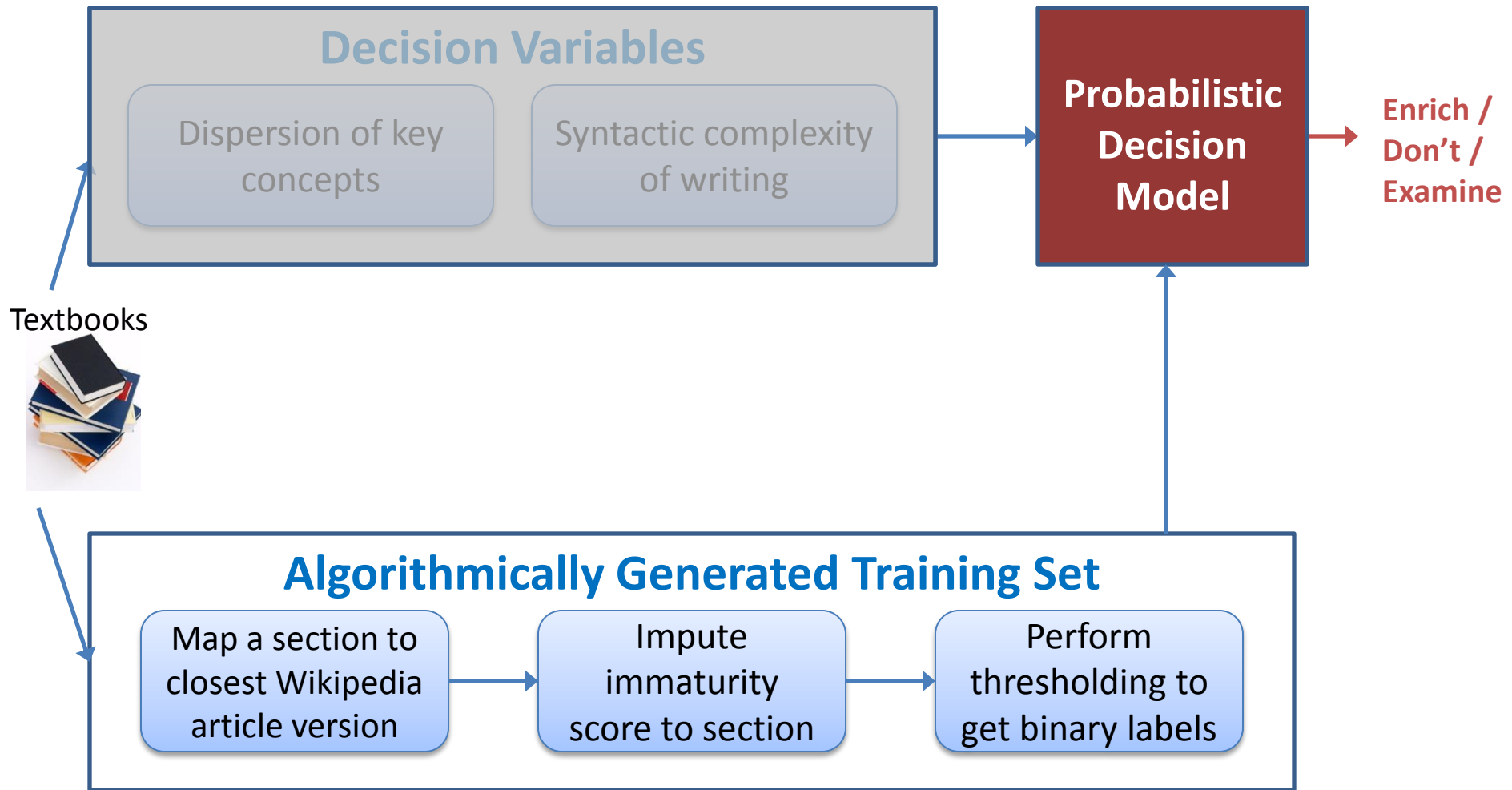
Decision Variables

Dispersion of key
concepts

Syntactic complexity
of writing

- Direct use of *Readability formulas* yielded poor results
- Variables abstracted from readability formulas:
 - Word length: Average syllables per word (S/W)
 - Sentence length: Average words per sentence (W/T)
- Larger syntactic complexity → greater need for augmentation

System Overview



Probabilistic Decision Model

- Probabilistic scoring of a section needing enrichment through logistic regression
- Probability that a section needs enrichment

$$P(y = 1 | \mathbf{z}, \mathbf{w}) = \frac{1}{1 + \exp \{ -(b + \mathbf{z}^T \mathbf{w}) \}}.$$

Section needing enrichment

Decision variables

Importance between decision variables

- Optimal weight vector \mathbf{w} learned from a training set of textbook sections
- Scores binned into
 - “Enrich”, “Don’t enrich”, or “Manually investigate to decide”

Algorithmically Generated Training Set

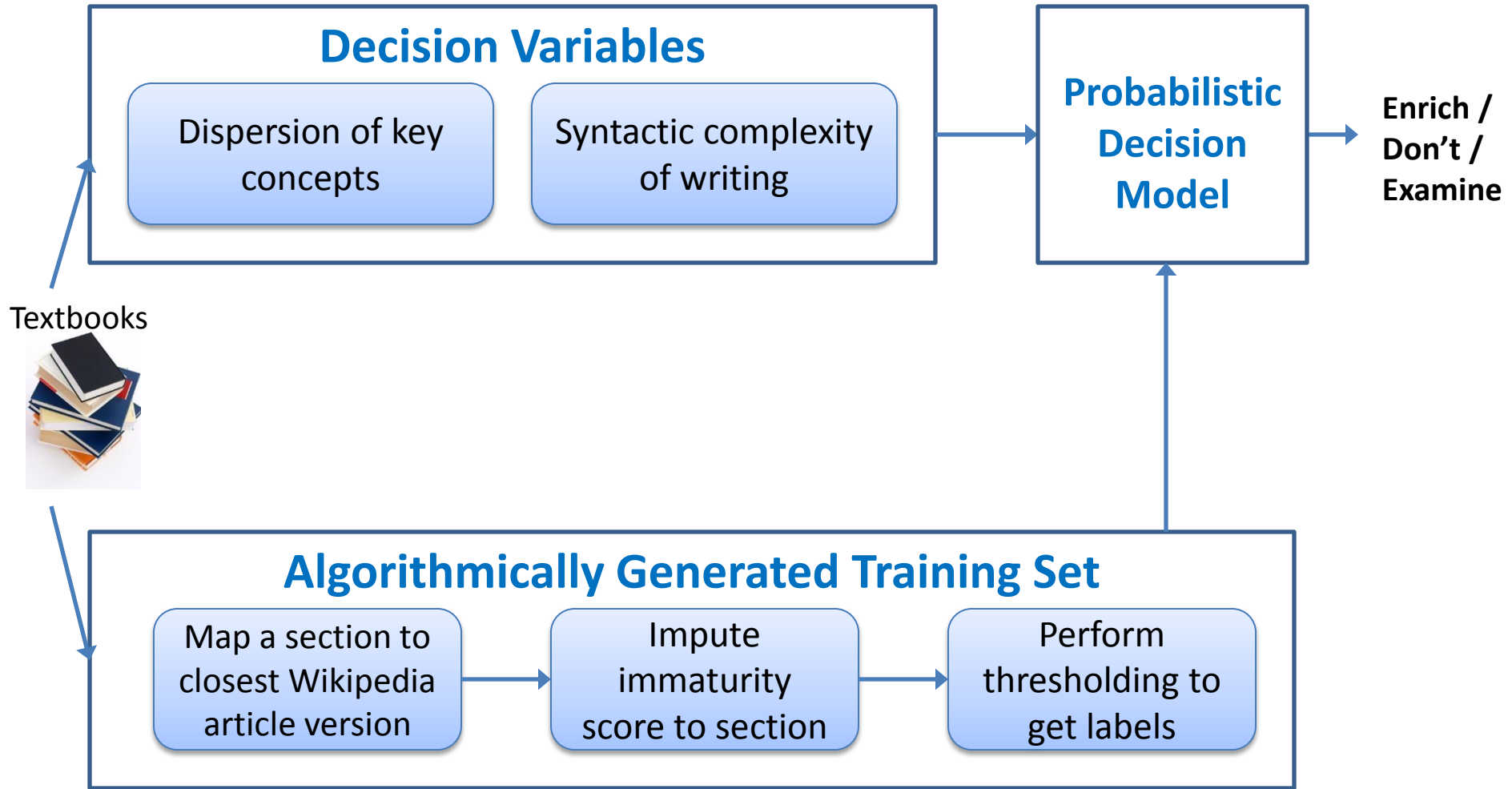
Map a section to
closest Wikipedia
article version

Impute
immaturity
score to section

Perform
thresholding to
get binary labels

- Difficult to get qualified judges who would give consistent labels
- Map a textbook section to a most similar version of a similar article in a versioned repository (Wikipedia)
- Compute immaturity of this version as a proxy for that of the section
- Immaturity: function of relative edits on each day and a time window K , with more weight to recent edits (see paper)
- Immaturity computation reliable at only extreme ends
 - But only few quality labels are needed

Sections Needing Enrichment



Application to Indian Textbooks



- Book corpus: 17 high school textbooks published by NCERT*
 - Grades IX – XII
 - Subject areas: Sciences, Social Sciences, Commerce, Math
 - 191 chapters, 1313 sections
- Followed by millions of students
- Available online

Results: Sections needing enrichment

CHAPTER 2

FORMS OF BUSINESS ORGANISATION

2.7 CHOICE OF FORM OF BUSINESS ORGANISATION

After studying various forms of business organisations, it is evident that each form has certain advantages as well as disadvantages. It, therefore, becomes vital that certain basic considerations are kept in mind while choosing an appropriate form of

(ii) Liability: In case of sole proprietorship and partnership firms, the liability of the owners/partners is unlimited. This may call for paying the debt from personal assets of the owners. In joint Hindu family business, only the *karta* has unlimited liability. In cooperative societies and companies, however, liability is limited and creditors can force payment of their claims only to the extent of the company's assets.

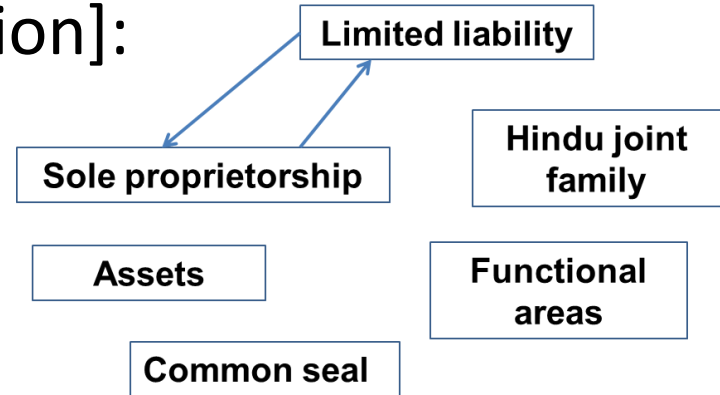
above are inter-related. Factors like capital contribution and risk vary with the size and nature of business, and hence a form of business organisation that is suitable from the point of view of the risks for a given business when run on a small scale might not be

operations. Cooperative societies and companies have to be compulsorily registered. Formation of a company involves a lengthy and expensive legal procedure. From the point of view of initial cost, therefore, sole proprietorship is the preferred form as it involves least expenditure. Company form of organisation, on the other hand, is more complex and involves greater costs.

in nature and require professionalised management, company form of organisation is a better alternative. Proprietorship or partnership may be suitable, where simplicity of operations allow even people with limited skills to run the business. Thus, the nature of operations and the need for professionalised management affect the choice of the form of organisation.

(v) Capital considerations: Companies organisations one by one. In Table 2.5, we analysed characteristics of different forms of organisations taken together so as to enable you to understand on a comparative basis as to where a form of organisation stands in comparison to others in respect of select features.

- Many unrelated concepts [high dispersion]:



- Long sentences, e.g.,
 - *Factors like capital contribution and risk vary with the size and nature of business, and hence a form of business organisation that is suitable from the point of view of the risks for a given business when run on a small scale might not be appropriate when the same business is carried on a large scale.*

Results: Sections *not* needing enrichment

Chapter Eight

ELECTROMAGNETIC

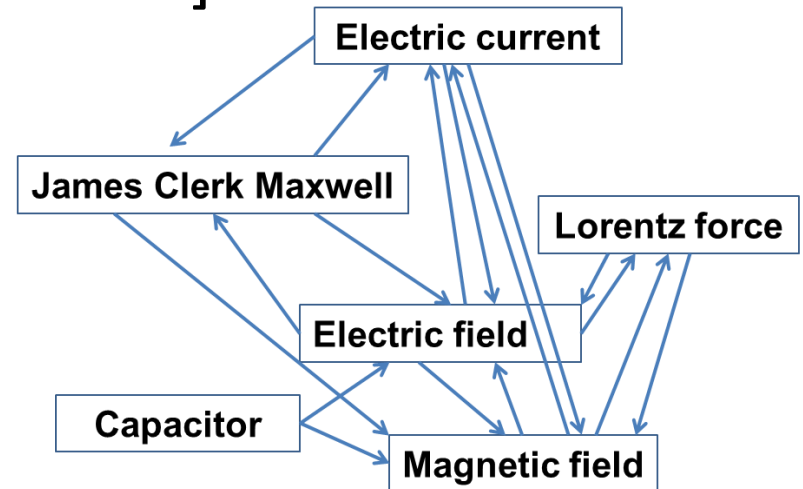
8.1 INTRODUCTION

In Chapter 4, we learnt that an electric current produces magnetic field and that two current-carrying wires exert a magnetic force on each other. Further, in Chapter 6, we have seen that a magnetic field changing with time gives rise to an electric field. Is the converse also true? Does an electric field changing with time give rise to a magnetic field? James Clerk Maxwell (1831-1879), argued that this was indeed the case – not only an electric current but also a time-varying electric field generates magnetic field. While applying the Ampere's circuital law to find magnetic field at a point outside a capacitor connected to a time-varying current, Maxwell noticed an inconsistency in the Ampere's circuital law. He suggested the existence of an additional current, called by him, the displacement current to remove this inconsistency.

Maxwell formulated a set of equations involving electric and magnetic fields, and their sources, the charge and current densities. These equations are known as Maxwell's equations. Together with the Lorentz force formula (Chapter 4), they mathematically express all the basic laws of electromagnetism.

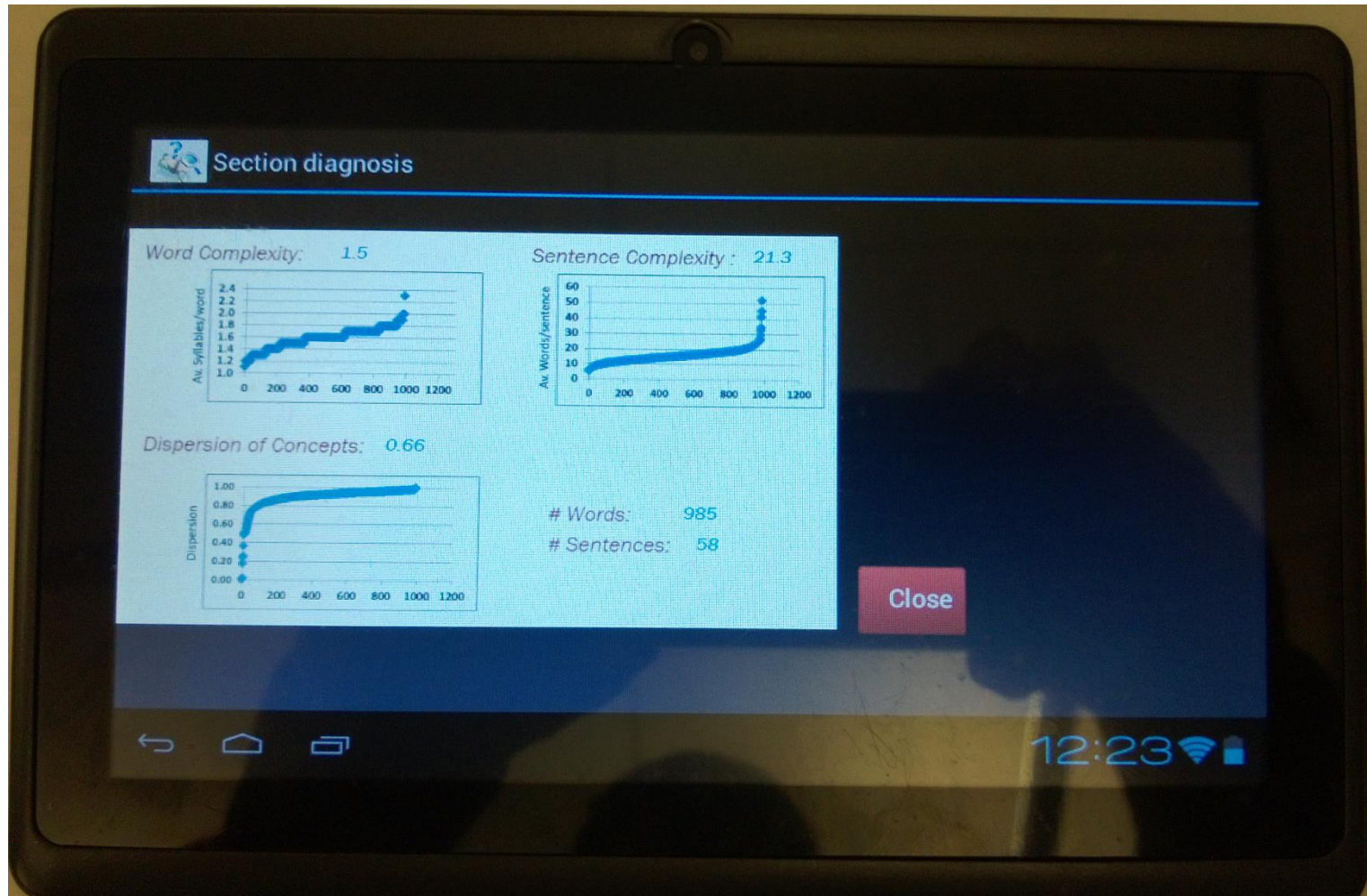
The most important prediction to emerge from Maxwell's equations is the existence of electromagnetic waves, which are (coupled) time-varying electric and magnetic fields that propagate in space. The speed of the waves, according to these equations, turned out to be very close to

- Highly related concepts [low dispersion]:

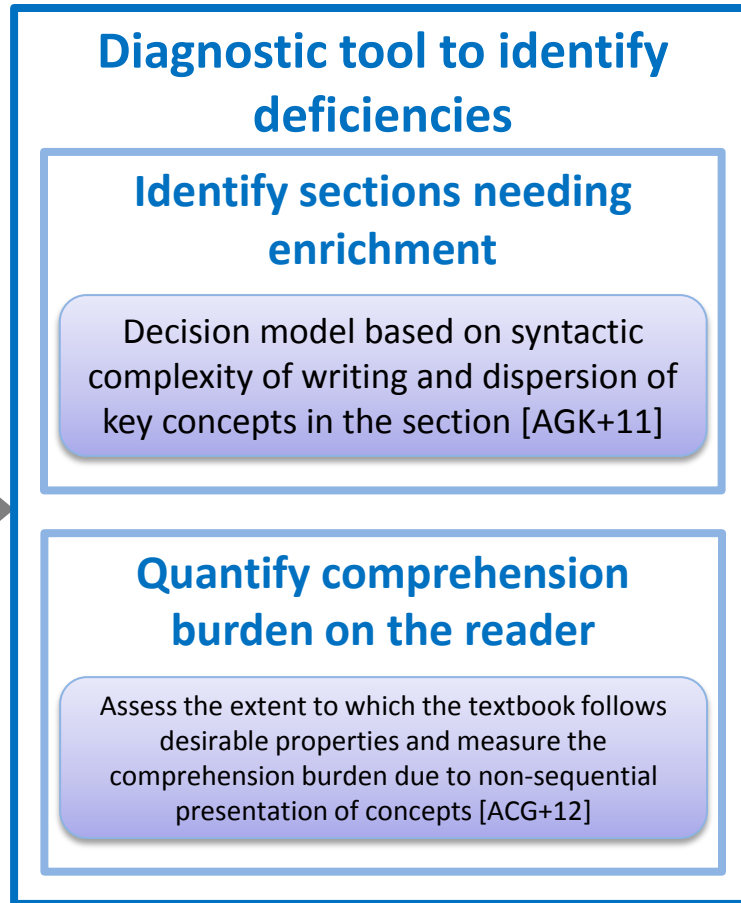


- Written clearly with simple sentences [low syntactic complexity]

Aakash Implementation



Data Mining for Enriching Textbooks



Augmenting book sections with web content

Add selective links to articles

Determine key concepts in each section of a book and find links to authoritative web articles for these concepts [AGK+11]

Add selective images

Find images most relevant for a section factoring in images in other sections [AGK+11]

Add selective videos

Find appropriate videos for a section

Vetted on high school textbooks (NCERT, India): Grades IX – XII
Across subjects

[AGK+11] [Data Mining for improving Textbooks](#), SIGKDD Explorations, 13(2), 2011 (summary of 3 earlier papers).
[ACG+12] [Empowering Authors to Diagnose Comprehension Burden in Textbooks](#), KDD 2012.

A section from an Economics Textbook

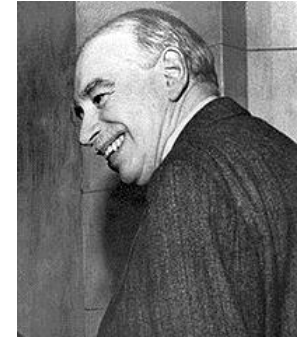
1.1 EMERGENCE OF MACROECONOMICS

Macroeconomics, as a separate branch of economics, emerged after the British economist **John Maynard Keynes** published his celebrated book *The General Theory of Employment, Interest and Money* in 1936. The dominant thinking in economics before Keynes was that all the labourers who are ready to work will find employment and all the factories will be working at their full capacity. This school of thought is known as the classical tradition. However, **the Great Depression** of 1929 and the subsequent years saw the output and employment levels in the countries of Europe and North America fall by huge amounts. It affected other countries of the world as well. Demand for goods in the market was low, many factories were lying idle, workers were thrown out of jobs. In USA, from 1929 to 1933, **unemployment rate** rose from 3 per cent to 25 per cent (unemployment rate may be defined as the number of people who are not working and are looking for jobs divided by the total number of people who are working or looking for jobs). Over the same period aggregate output in USA fell by about 33 per cent. These events made economists think about the functioning of the economy in a new way. The fact that the economy may have long lasting unemployment had to be theorised about and explained. Keynes' book was an attempt in this direction. Unlike his predecessors, his approach was to examine the working of the economy in its entirety and examine the interdependence of the different sectors. The subject of macroeconomics was born.

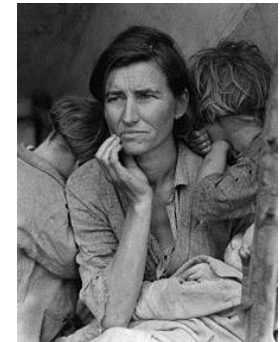
Augmented Section

1.1 EMERGENCE OF MACROECONOMICS

Macroeconomics, as a separate branch of economics, emerged after the British economist **John Maynard Keynes** published his celebrated book *The General Theory of Employment, Interest and Money* in 1936. The dominant thinking in economics before Keynes was that all the labourers who are ready to work will find employment and all the factories will be working at their full capacity. This school of thought is known as the classical tradition. However, **the Great Depression** of 1929 and the subsequent years saw the output and employment levels in the countries of Europe and North America fall by huge amounts. It affected other countries of the world as well. Demand for goods in the market was low, many factories were lying idle, workers were thrown out of jobs. In USA, from 1929 to 1933, **unemployment rate** rose from 3 per cent to 25 per cent (unemployment rate may be defined as the number of people who are not working and are looking for jobs divided by the total number of people who are working or looking for jobs). Over the same period aggregate output in USA fell by about 33 per cent. These events made economists think about the functioning of the economy in a new way. The fact that the economy may have long lasting unemployment had to be theorised about and explained. Keynes' book was an attempt in this direction. Unlike his predecessors, his approach was to examine the working of the economy in its entirety and examine the interdependence of the different sectors. The subject of macroeconomics was born.



John Maynard Keynes



The Great Depression formed the backdrop against which Keynes's revolution took place. The image is Dorothea Lange's Migrant Mother depiction of destitute pea-pickers in California, taken in March 1936.

Augmenting Textbooks with Images

Image Mining

Image Assignment

Obtain images relevant to each section using complementary methods

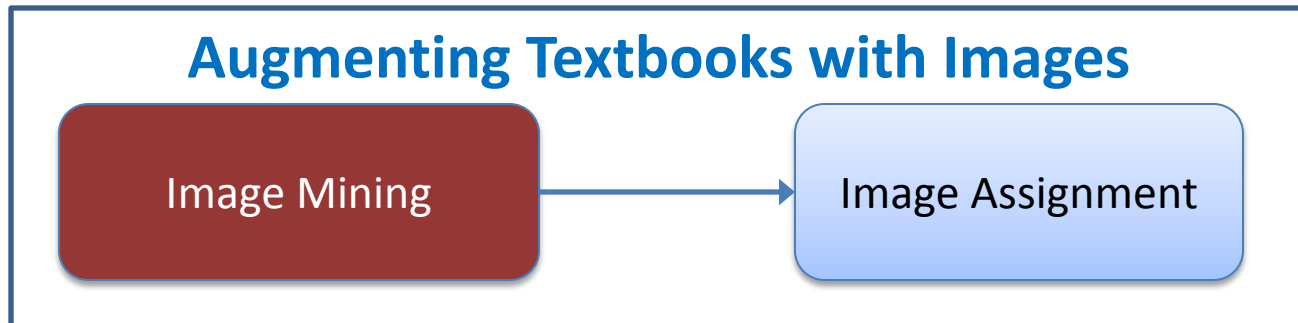
Comity: Leverage image search provided by search engines

Affinity: Leverage image metadata on webpages

Allocate most relevant images to each section such that

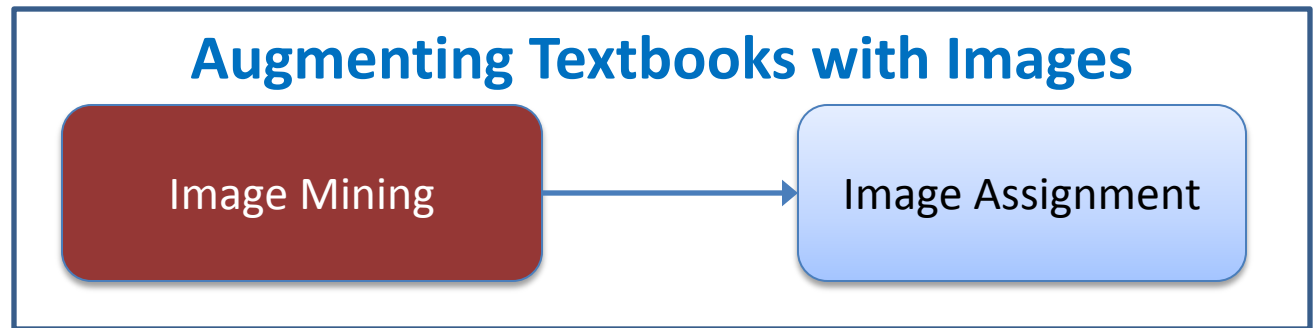
- Each section is augmented with at most k images
- No image repeats across sections

Comity



- Intuition: Combine results of a large number of short, but relevant queries
 - Search engines barf on long queries (such as entire section content)
- Identify key concepts present in a section, C
- Form two-concept and three-concept queries, Q
- For each $q \in Q$, obtain ranked list of images $I(q)$ using image search
- Relevance score(i) of image i =
$$\sum_q f(\text{position of image in } I(q), \text{ importance of concepts in } q)$$

Affinity



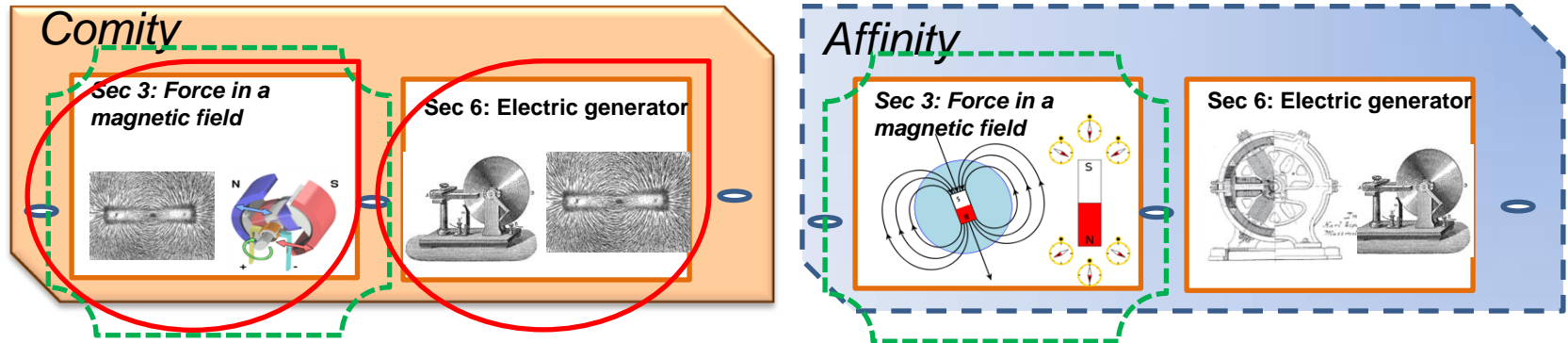
- Intuition: Authoritative pages contain authoritative images
- Identify top webpages that have high textual similarity with the given book section s
- Score each image i in these pages based on a similarity metric
 - $\text{Relevance}(i, s) = f(\text{metadata associated with the image } i, \text{key concepts in } s)$
 - Metadata: captions, content relevant to the image, etc.

Augmenting Textbooks with Images

Image Mining

Image Assignment

1. Complementary algorithms provide a broad selection of images for a section



2. But images can repeat across sections because of independent mining at section level

Augmenting Textbooks with Images

Image Mining

Image Assignment

MaxRelevantImageAssignment

$$\max \sum_{i \in I} \sum_{j \in S} x_{ij} \cdot \lambda_{ij}$$

Relevance score of image i to section j

Total relevance score for the chapter: sum of relevance scores of images assigned

s.t.

$$x_{ij} \in \{0, 1\} \quad \forall i \in I \forall j \in S$$

=1 if image i is selected for section j else 0

$$\sum_{i \in I} x_{ij} \leq K_j \quad \forall j \in S$$

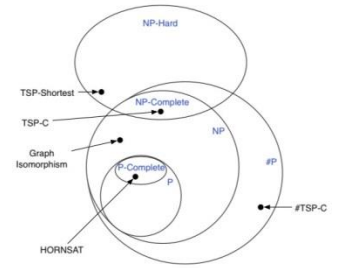
Constraint: At most K_j images can be assigned to section j

$$\sum_{j \in S} x_{ij} \leq 1 \quad \forall i \in I$$

Constraint: An image can belong to at most one section

Solution Technique

MaxRelevantImageAssignment
*can be solved optimally in
polynomial time*



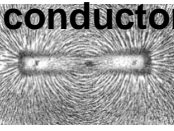
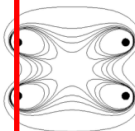


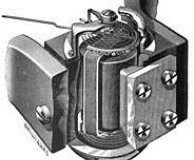
Proof: Follows from an efficient reduction to the Maximum Weighted Bipartite Matching problem

(Algorithm immediate from the proof)

Value of Image Assignment

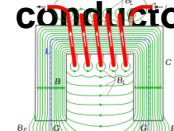


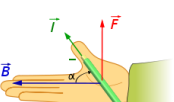

BEFORE IMAGE ASSIGNMENT

Sec 2: Magnetic field due to a current carrying conductor

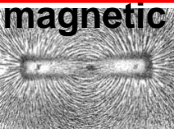
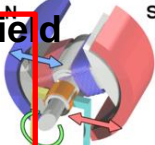
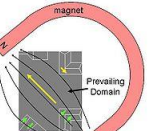


Magnetic effect
Helmholtz Contour
Solenoid
Amperemeter
Galvanometer

Sec 2: Magnetic field due to a current carrying conductor


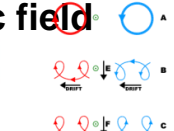
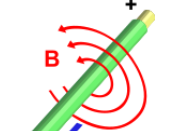
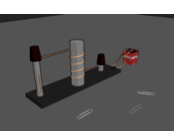
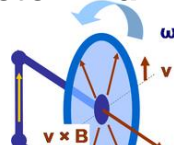
Magnetic field
Simple electromagnet
Right hand rule
Right hand rule
Solenoid

Sec 3: Force on a current carrying conductor in a magnetic field

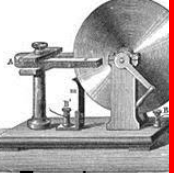
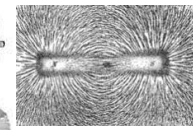
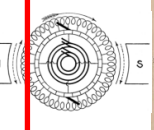

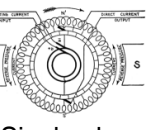
Magnetic effect
Electric motor cycle
Effect of magnet on domains
Meissner Effect
Descartes' magnetic field

Sec 3: Force on a current carrying conductor in a magnetic field

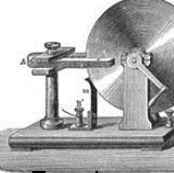
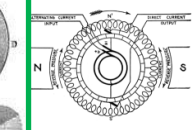
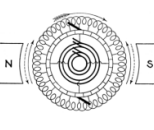
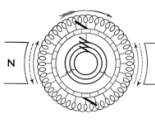

Electric motor cycle exploits electro magnetism
Drift of charged particles
Magnetic field around current
Electromagnets attract paper clips...
Faraday's disk electric generator

Sec 6: Electric generator

Faraday disk generator
Magnetic effect
Two phase rotary converter
Descartes' magnetic field
Single phase rotary converter

Sec 6: Electric generator

Faraday disk generator
Single phase rotary converter
Two phase rotary converter
Three phase rotary converter
Descartes' magnetic field

Same images repeat across sections!

Richer set of images to augment the section

Evaluation on NCERT Textbooks

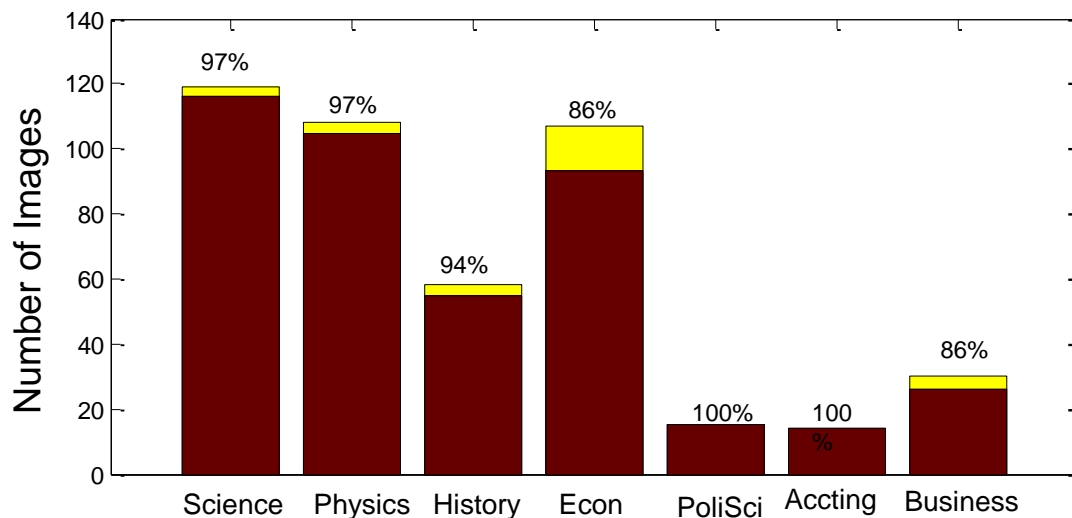


- User-study employing Amazon Mechanical Turk to judge the quality of results
- HIT (User task): A given image helpful for understanding the section?
- An image deemed helpful if the majority of 7 judges considered it so
- Helpfulness index:
 - Average of helpfulness score of the images over all sections

Agrawal et al. CIKM 2011.

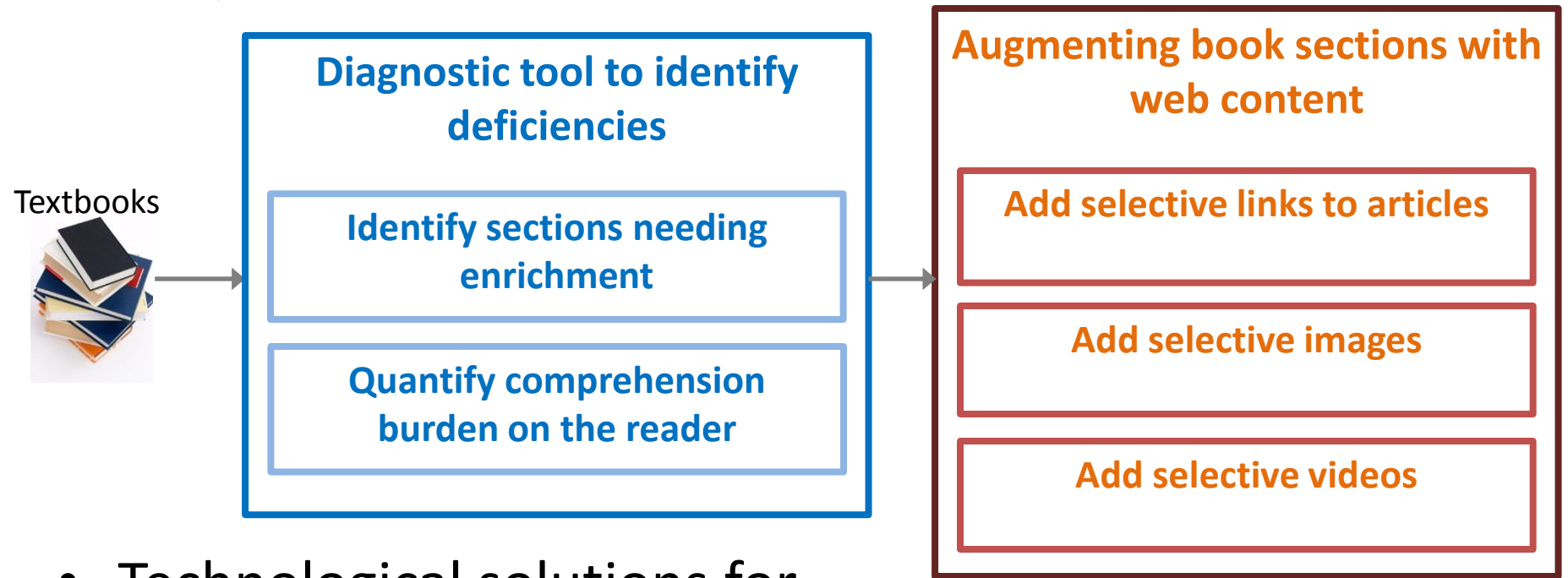
Performance

The number above a bar indicate helpfulness index for the corresponding subject (% of images found helpful)



- 94% of images deemed helpful
- Performance maintained across subjects

Recap



- Technological solutions for
 - Diagnosing deficient sections
 - Mining and optimal placement of web objects (articles, images & videos)
- Promising results over High School textbooks across subjects and grades

Outline



- Importance of electronic textbooks
- Enriching textbooks through data mining
- **Research opportunities**
- Concluding thoughts

Textbook Augmentation



- Deeper analysis to identify key concepts discussed in a section (Discourse analysis? Formal Concept Analysis?)
- Caption and placement of augmentations
- Extension to other multimedia types (audio, simulations)
- Modeling for “appropriateness” of augmentations
 - Mining of user-interactions

Broader Questions



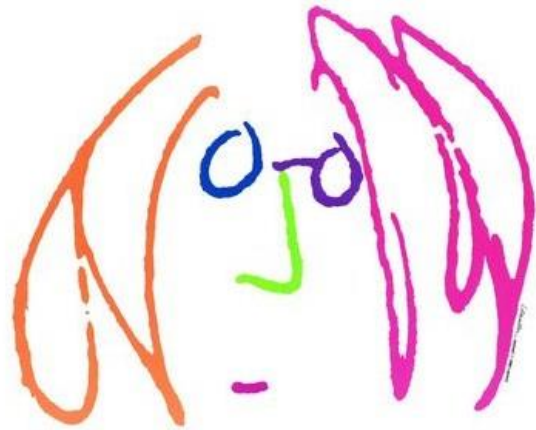
- Social networking centered around an electronic textbook
- Complementarity of algorithmic solutions to the crowdsourcing approaches
 - Tools for capturing feedback on textbooks (errors, better explanations, supplementary material, etc.)
 - Trust and ranking
- Deployment issues:
 - Social, behavioral, legal, cultural, policy, and political issues
 - Quantifying impact

Outline



- Importance of electronic textbooks
- Enriching textbooks through data mining
- Research opportunities
- **Concluding thoughts**

Call to Action



I M A G I N E 
John Lennon

- Thomas Friedman: “Big breakthroughs happen when what is possible meets what is desperately necessary”
- The stage is set for data community to help revolutionize education
- The present audience can (and should) play key role
 - We are hiring 😊

References

- [1] Rakesh Agrawal, Sreenivas Gollapudi, Krishnaram Kenthapadi, Nitish Srivastava, Raja Velu. "[Enriching Textbooks Through Data Mining](#)". [DEV 2010](#).
- [2] Rakesh Agrawal, Sreenivas Gollapudi, Anitha Kannan, Krishnaram Kenthapadi. "[Identifying Enrichment Candidates in Textbooks](#)". [WWW 2011](#).
- [3] Rakesh Agrawal, Sreenivas Gollapudi, Anitha Kannan, Krishnaram Kenthapadi. "[Enriching Textbooks With Images](#)". [CIKM 2011](#).
- [4] Rakesh Agrawal, Sunandan Chakraborty, Sreenivas Gollapudi, Anitha Kannan, Krishnaram Kenthapadi. "[Empowering Authors to Diagnose Comprehension Burden in Textbooks](#)". [KDD 2012](#).
- [5] Rakesh Agrawal, Maria Christoforaki, Sreenivas Gollapudi, Anitha Kannan, Krishnaram Kenthapadi, Adith Swaminathan. "[Augmenting Textbooks with Videos](#)". Working Paper. 2013.
- [6] Rakesh Agrawal, Sreenivas Gollapudi, Anitha Kannan, Krishnaram Kenthapadi. "[Studying from Electronic Textbooks](#)". Working Paper. 2013.
- [7] Ceren Budak, Rakesh Agrawal. "[On participation in Group Chats in Twitter](#)". [WWW 2013](#).

Thank you!



Augmenting with Videos

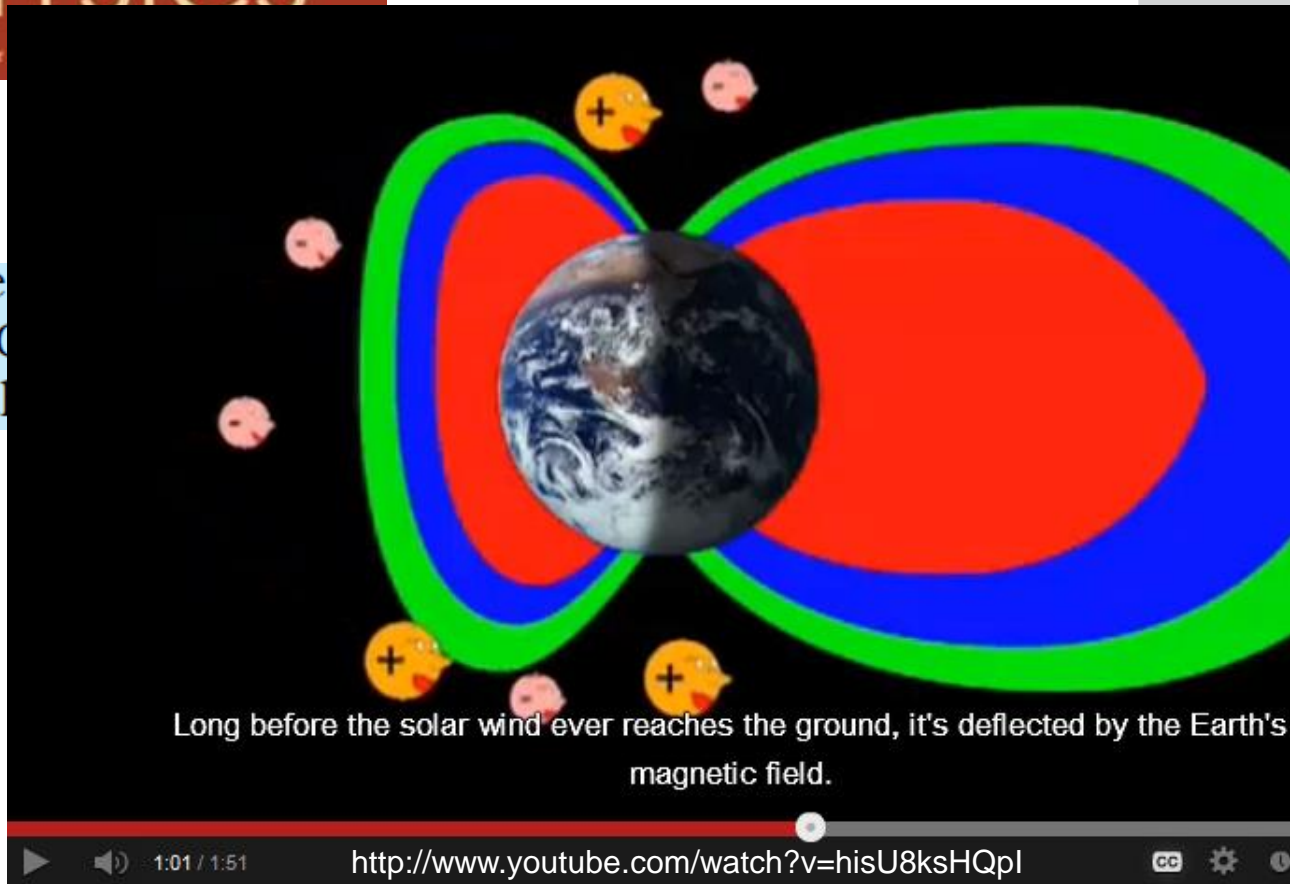
PHYSICS

Textbook for

Magnetism and Matter

The study of... called the

also an... with and be... netic field



"Can you feel a solar wind?" (Ask an Astronomer)



SpitzerScienceCenter · 88 videos

Dr. Robert Hurt explains what a solar wind is, and how it affects us here on Earth.

Improving Education



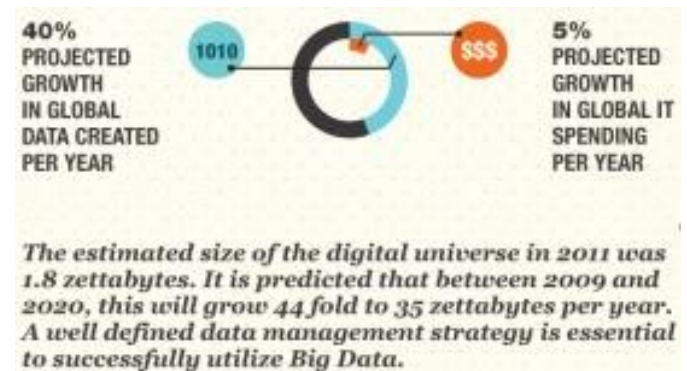
- Identification of ill-matched material
 - Test score = f (student ability, suitability of material)
 - Learning: Item Response Theory
- Collaborative translation and localization of educational material
- Analysis of new pedagogical approaches

Defining Big Data: 3 V's

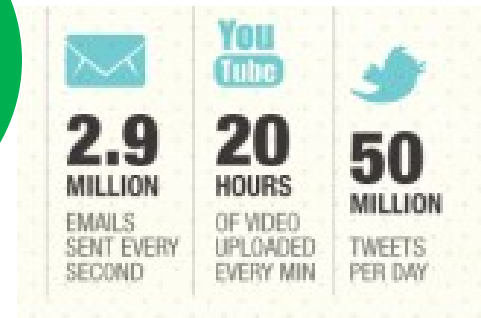
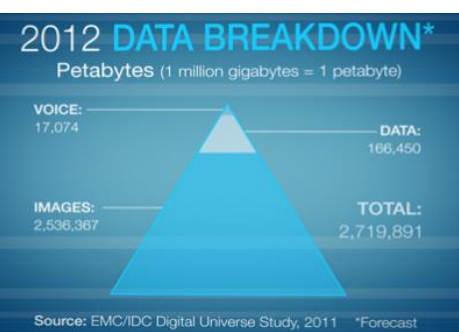
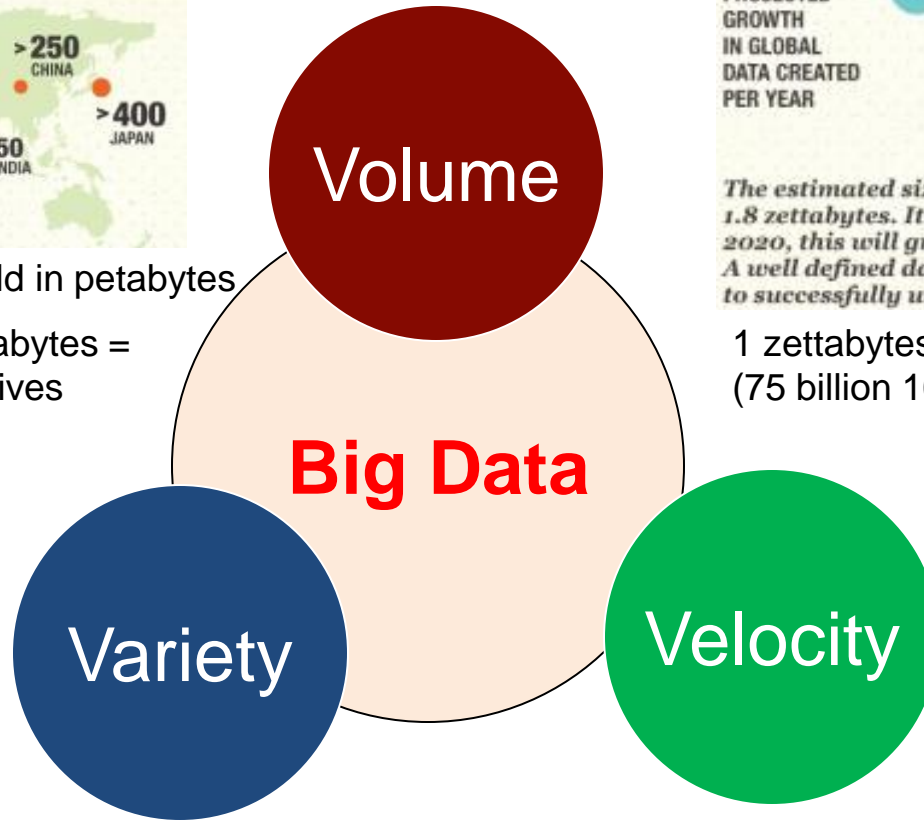


Data stored across the world in petabytes

1 petabytes = 1 million gigabytes =
1,000 one-terabyte hard drives



1 zettabytes = 1 million petabytes
(75 billion 16 GB Apple iPads)



Doug Laney. 3D Data Management: Controlling Data Volume, Velocity, and Variety. Meta. Feb. 2001.