
Information Retrieval and Web Search Question Answering Systems

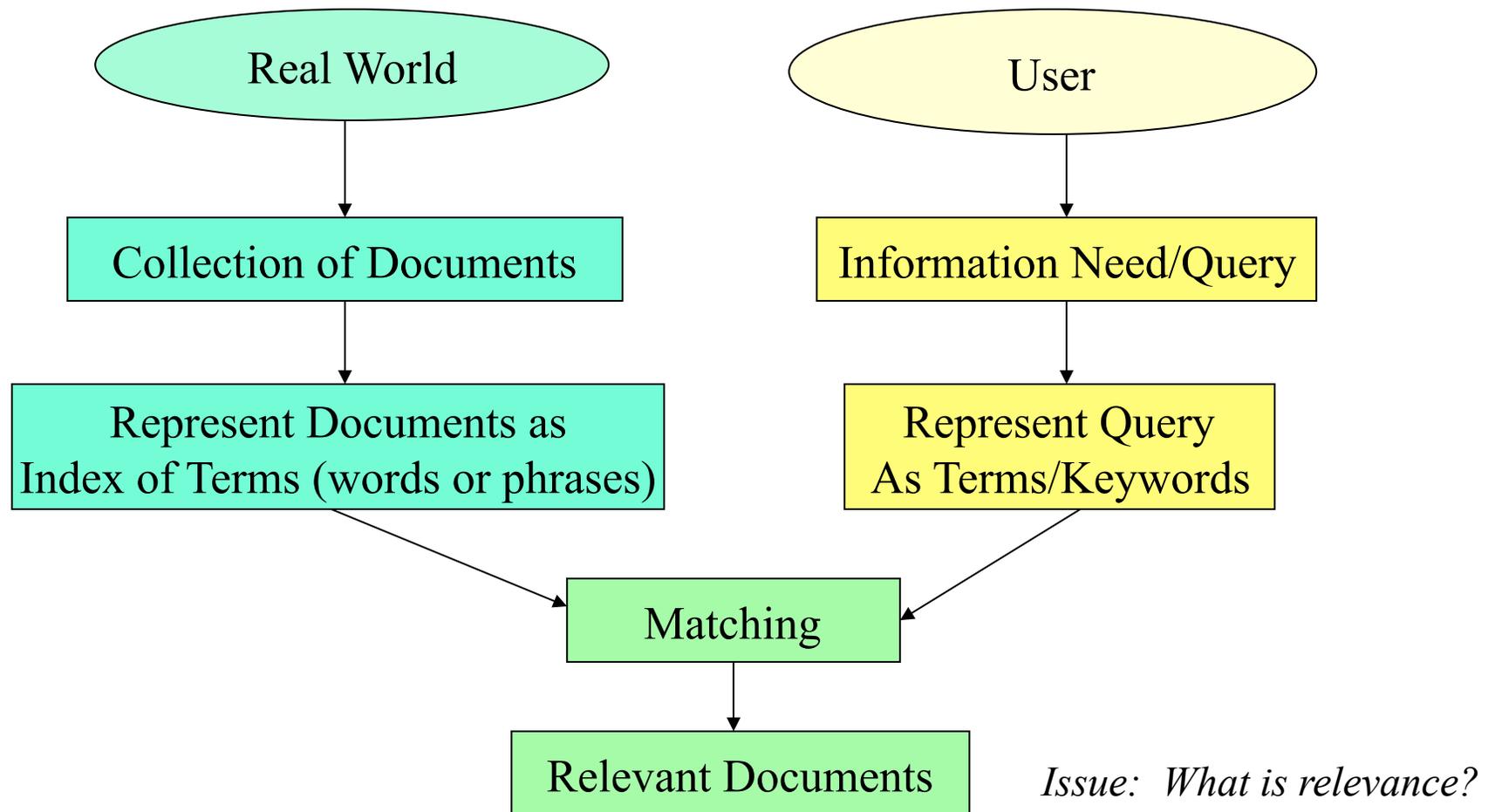
What is Information Retrieval

- Gerard Salton, 1968:
Information retrieval is a field concerned with the structure, analysis, organization, storage, searching and retrieval of information
- Manning, Raghavan and Schutze, 2008:
Information Retrieval (IR) is finding material (usually documents) of an unstructured nature (usually text) that satisfies an information need from within large collections (usually stored on computers)
 - “Document” is the generic term for an information holder (book, chapter, article, webpage, etc)

What is tough about IR?

- One issue is how to **represent documents** so others might retrieve them
 - Need to match the text of the document with the query
 - In full, free-text systems this is an issue because documents and queries are expressed in language
 - and language is synonymous and polysemous
 - methods for solving the language issue are difficult
 - Sometimes called the **vocabulary gap** or mismatch
- Given the retrieval of some documents how to decide which ones are **most relevant** to the user's query
 - Most often implemented as a **ranking** of the resulting documents

Typical Information Retrieval System



IRS Research

- Traditional IR System research assumes that a user is interested in finding out information on a particular topic
- TREC collections and research experiments at NIST/Text REtrieval Conference (TREC): <http://trec.nist.gov>
 - build IR systems with different retrieval models
 - test against a standard collection of newswire documents
 - human evaluators judge relevant documents
 - report system evaluations in terms of precision and recall
 - Example type of query:

I am interested in all documents that discuss oil reserves and current attempts to find new reserves, particularly those that discuss the international financial aspects of the oil production process.

Information Needs

- Other branches of research focus on the user and whether the user's underlying information seeking is satisfied
- Early theories by Belkin, Oddy, etc.
 - Functions of the retrieval system to model the user's information need in an interactive retrieval session:
 - Characterize User
 - Get initial information need
 - Develop need context
 - Formulate information need
 - Conduct search for documents
 - Evaluate results
 - Feedback from user

Constructing the Index

- Process documents and identify terms to be indexed
 - Terms are often just the words
 - Usually stemming is applied and stop words removed
 - Sometimes basic noun phrases are also added, particularly proper names
- Compute weights of terms, depending on model definition
- Build index, a giant dictionary mapping terms to documents
 - For each term,
 - keep a list of documents that it occurs in
 - weights

Models

- Vector Space Models
 - Widely used weights known as TF/IDF (term frequency / inverted document frequency)
 - TF – frequency of the term in the document (normalized by document length)
 - Intuition: more frequently occurring terms are more important
 - IDF – invert the document frequency, the number of documents in the collection that the term occurs in
 - Intuition: terms occurring in all documents are less important to distinguish which ones are relevant to the query
- Other models include
 - Probabilistic models
 - Language models
 - Boolean models

Queries and matching

- Natural language queries are converted to terms, usually called keywords
 - In web search, typical queries are keywords already
- Query terms are used to retrieve documents from the index
- Model defines how to match query terms to documents, using the weights, and usually resulting in a score for each document
- Documents are returned in order of relevance

Evaluation

- Human judgments as to whether returned documents are relevant to the query
- Precision and recall can be used to evaluate a set of returned documents

| | Relevant | Non-Relevant |
|----------------------|------------------------|------------------------|
| Retrieved | a (true positives) | b (false positives) |
| Non-Retrieved | c (false negatives) | d (true negatives) |

$$\text{Precision} = a / a + b$$

$$\text{Recall} = a / a + c$$

Another Evaluation Measure

- The F-measure is a combination of recall and precision, averaged using the harmonic mean

- Let P be precision and R be recall

$$F = (\beta^2 + 1) PR / (\beta^2) P + R$$

- Typically, the measure is used for $\beta = 1$, giving equal weight to precision and recall

$$F_{\beta=1} = 2 PR / P + R$$

Evaluating Ranked Retrieval Results

- Precision-Recall Curves
 - Given the top k ranked documents, compute precision and recall
 - Plot precision vs. recall giving “sawtoothed” curve
 - or give precision vs. recall at 11 positions of recall
- Average Precision
 - Compute the average of precision over a sequence of recall levels
- Interpolated Average Precision
 - Interpolated precision at a recall level r is defined as the highest precision found at any recall level $r' \geq r$.

Sample “Recall Level Precision Averages” Table

| Recall Level Precision Averages | |
|---|------------------|
| Recall | Precision |
| 0.00 | 0.5857 |
| 0.10 | 0.3927 |
| 0.20 | 0.3252 |
| 0.30 | 0.2799 |
| 0.40 | 0.2521 |
| 0.50 | 0.2131 |
| 0.60 | 0.1776 |
| 0.70 | 0.1395 |
| 0.80 | 0.0885 |
| 0.90 | 0.0415 |
| 1.00 | 0.0118 |
| Average precision over all relevant docs | |
| Non-interpolated | 0.2109 |

Text Retrieval Conference (TREC)

- Co-sponsored by the National Institute of Standards and Technology (NIST) & the Defense Advanced Research Projects Agency (DARPA)
 - Begun in 1992
- Purpose is to support research within the information retrieval community by providing the infrastructure necessary for large-scale evaluation of text retrieval methodologies.
 - Provides document collections, queries and human judges
 - Main IR track was called the “Ad-Hoc Retrieval Track”
- Has grown in the number of participating systems and the number of tracks each year.
 - Tracks have included cross-language retrieval, filtering, question answering, interactive, web, novelty, video, ...

Improving Retrieval

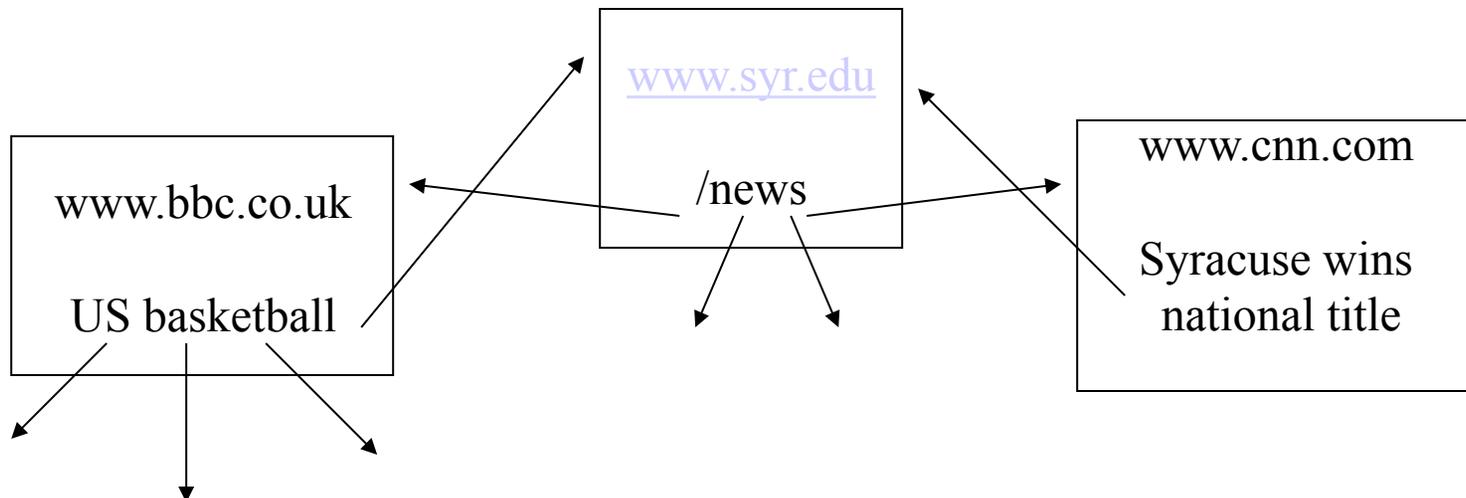
- Query expansion, adding semantically similar words or context words
 - For example, use WordNet to add synonyms to query terms
 - What sense to use? The first?
 - Results are mixed
 - Synonyms added for incorrect sense will throw results off badly
- Relevance Feedback
 - One technique consistently shown to improve retrieval
 - Human relevance feedback – after human has selected a few really relevant documents, add terms from those documents to the query
 - Pseudo-relevance feedback
 - Perform one retrieval and assume that the top n documents are relevant
 - Use those documents to add terms to the query

Web Search

- With the advent of the Web, basic IR was applied to this scenario of linked documents world wide
 - Company like Google keeps a **giant index** of documents for search
- Why/How would IR be different on the Web
 - Web behaves large, IR databases behave small
 - Databases are fielded at predictable times, sites update whenever
 - Collection frequencies needed for Inverse Document Frequency (IDF) are so impermanent
 - Quality control of documents on the web is not present
 - Links may not be permanent
 - No such thing as a complete inverted file for the entire web – many hidden pages (Deep Web)
 - Impact of pay for ranking
 - Web search companies do not reveal all of what they do with documents and queries

Web Graph

- View the collection of static web pages as a graph with “hyperlinks” between them
- Hyperlink in HTML, given by the anchor tag, will give the URL of another web page
 - in-degree is the number of links coming to a page from other pages
 - out-degree is the number of links on the page



Web Crawling

- In order to build an index of documents for web search, the web crawler, or spider, has to locate documents
- Required Features:
 - Robustness – it must not get stuck in dead ends or loops
 - Politeness – it must not overwhelm any web server with too fast or too many requests
 - web servers set politeness policies
- Desired Features
 - Quality – should try to give “useful” pages priority
 - Freshness – should obtain updated pages so that the web index has a fairly current version of the web page
 - Performance and efficiency, scalability, operate in a distributed fashion

Web Document Processing

- Find content and process into tokens for traditional use in IR indexing
 - content may be text in-between tags
 - image tags may have text attributes to describe the image
 - may discard javascript and other computational elements
 - may even try to discard “noisy” text in the form of web site navigation, standard copyright notices, etc.
 - one technique is to observe that real content text has fewer tags per token than non-content text
- Keywords may be added to the document that don’ t appear directly in the content
 - metadata tags may have keywords
 - special weights may be added for tokens appearing in header tags
 - anchor text from other pages (see next slide)
- Look at on-line example “view page source”

Anchor Text

- Sometimes the text content of a web page does not contain generally descriptive words for that page
 - example: home page for IBM does not contain the word “computer”
 - home page for Yahoo does not contain the word “portal”
- Generally descriptive words may be found in anchor text of links, or even near it, that occur in other pages
 - ` Big Blue `
 - ``
example of a large computing firm ``
 - ` Big Blue `
 - an example of a large computing firm is
` here `
 - typically, we disregard anchor text words such as “click” and “here”

Link Analysis for Document Ranking

- Link analysis can be viewed as a development of citation analysis for the web
 - Bibliographic citation analysis used book and article references
 - Bibliometric analysis of bibliographic citation links
 - Web examples: Web of Science from ISI / Citeseer
- The intuition behind link analysis is that a hyperlink from page A to page B represents an endorsement of page B, by the creator of page A.
 - not true for some links, such as links to administrative notices on corporate websites - “internal” links are typically discounted.
- Two major algorithms, PageRank and HITS, that give scoring weights for web pages
 - such weights are combined with other weights from content tokens and many other ranking criteria

Additional Criteria for Ranking

- Popularity – what are the current topics of the day?
 - Collected from blogs and previous queries
- Click-through results – statistics about which pages users click-on after getting ranked results can inform ranking algorithms to improve later rankings
- Context – keep track of the user's interests, location, situation
 - What do other users like this one like?
- Learning to rank – use machine learning on ranked relevance results to improve rankings
 - Importance of getting relevant documents in the top 10 list
 - Search engine companies have large amounts of data, including relevance judgments in terms of what documents users click on after a query

Search Engine Company Data Centers

- Google has designed data centers specifically for web search
 - Uses lots of low-cost computers networked together
 - Design network and data algorithms for fast performance
 - About 2 dozen data centers around the world
 - Each data center has up to 10,000 computers
 - Data center at The Dalles, Oregon



Question Answering (QA)

- IR assumes that the user wants an entire document, QA assumes that the user wants a small, focused text result that answers a question
- Answers may not only be phrased with different vocabulary, but they may be implied by other statements or facts
Q: *What year did Marco Polo travel to Asia?*
A: *Marco polo divulged the truth after returning in 1292 from his travels, which included several months on Sumatra.*
- QA systems must apply more NLP analysis to text in order to find the answers to questions
- The document collections of QA systems range in size from the Web to a targeted collection of documents such as a company's product documents

Typical QA System

- QA systems apply a two-step strategy
 - The document collection of a QA systems is too large to apply the (time-consuming) NLP processing to all the documents
 - First, use IR to retrieve a set of relevant documents
 - Then process those documents with NLP techniques
 - Identify answers in the documents

Factoid Questions (from TREC)

- *Where is Belize located?*
- *What type of bridge is the Golden Gate Bridge?*
- *What is the population of the Bahamas?*
- *How far away is the moon?*
- *What is Francis Scott Key best known for?*
- *What state has the most Indians?*
- *Who invented the paper clip?*
- *How many dogs pull a sled in the Iditarod?*
- *Where did bocci originate?*
- *Who invented the electric guitar?*
- *Name a flying mammal?*
- *How many hexagons are on a soccer ball?*
- *Who is the leader of India?*

TREC Question Answering Track

- Goal: encourage research into systems that return actual answers
 - From 1999 – 2004 in various forms
- Questions were short and fact based
 - From Encarta and Excite search logs
- Extract or construct answer from set of documents
- For each question
 - Supply up to five ranked answer submissions
 - With the most likely answer ranked first
 - Answer strings were evaluated by NIST's human assessors for correctness
- Evaluation: Mean-Reciprocal Rank (MRR) – score given is the reciprocal of the rank of the first correct answer

Evaluation of Answers

- How much of an answer is enough?

Q: Where will the 2002 winter Olympics be held?

Text: The 2002 Winter Olympics will be held in beautiful Salt Lake City, Utah.

A1: beautiful Salt Lake City, Utah

A2: Salt Lake City, Utah

A3: Salt Lake City

A4: Salt Lake

A5: Utah

- The questioners would probably prefer an entire sentence that established an authority for the answer, perhaps with the answer text highlighted.

Question Classification

- Questions are classified by an answer type taxonomy or question ontology
 - Usually hand-built, but sometimes automatically learned from hand annotated questions
 - Includes types of entities to be found as an answer
 - “Who founded Virgin Airlines?” Expected type: Person
 - “What Canadian city has the largest population?” City
 - Also Location, Time, Quantities etc. (Where, How long, How much)
 - Or more specifically for Flower, Human Description, Human Group, Human Individual, etc.
 - See Figure 23.9 in J&M
 - Other Question types
 - Definition questions, reasons (to answer why questions)
 - Special forms such as birth and death dates
 - “When did George Washington die?”

Passage Retrieval

- Separate retrieved documents into passages that may contain answer and rank them
- Common criteria for ranking passages
 - Number of query words in the passage
 - Number of words semantically similar to query words
 - Proximity of query words and semantically similar words to each other in the passage
 - Contains expected answer type
 - Proximity of query words and semantically similar words to expected answer types

Answer Processing

- Approaches typically have a suite of answer processing modules that use different techniques to find the answer
- Some are specific to particular question types and expected answer types
- For questions that are looking for particular entity types, find sentences with those types
 - For example, if question is looking for Person, return sentences with named entities of type Person
 - Rank those sentences according to presence of question words
Q: “Who is the prime minister of India?”
Answer sentence: “Monmohan Singh, Prime Minister of India, has told leaders . . . “

Specialty Answer Processing

- Some question types, such as those querying when someone is born or died, are often answered with a fairly small set of sentence constructions
- A special purpose module may be built that contains a number of the patterns of those sentences
 - Often hand-built regular expression patterns
 - Define patterns of sentences to answer the question
 - Use parsed sentences to match those patterns
 - Patterns include subject/verb forms
 - Appositions
 - Known relations for that type of question
 - Many others

Answer patterns

- Query Reformulation
 - Rephrase query as a partial answer sentence “Virgin Airlines was founded by X” and try to find semantically similar sentences
- The Web approach
 - Since there are potentially millions of documents on the Web that could answer this question, assume that there is one that answers the question in the same form and vocabulary as the question
 - Search the web to find the answer in the right form

Deeper semantic reasoning

- Query Reformulation
 - Rephrase query as a partial semantic relation
Founded (X, Virgin Airlines)
and try to find or infer instances of this relation from the text
- Semantic processing of the text may have
 - Relation extraction
 - Parsing and semantic role labeling, using the semantic roles as relations (and identifying semantically similar verbs)

“Richard Branson formed Virgin Atlantic Airways in 1984, launched Virgin Mobile in 1999, . . . “

 - Will also need to use knowledge sources such as gazeteers, and some relations such as “near”
 - Experiments with using other forms of real-world knowledge

Selecting the final answer(s)

- In approaches with multiple answer modules, the results must be combined
 - Answer ranking
 - Confidence levels
- Often difficult to produce comparable confidence scores from different modules

IBM's Watson

- Deep QA project, headed by David Ferrucci *
 - Similar system architecture to typical systems but bigger and faster
- Watson interface allowed the Deep QA system to be used to play Jeopardy by selecting questions, deciding when to “ring in” with a confident answers and how to bet



* Ferrucci: Introduction to “This is Watson”, IBM Journal of Research, 2012

IBM's Watson

- Real time challenge
 - Need answers in under 3 seconds
 - Optimized hardware, based on IBM Power 7, and software
 - Distributed parallel computing for answer modules
- Incorporated NLP, Machine Learning, Knowledge representation
- Question categories contribute to expected answer types
 - Some are entity types:
 - Vice presidents, Canadian cities, Characters in classic literature,
 - Some are more complex:
 - Rhyme time, Starts with “A”

Jeopardy Example Topics and Questions

Recent History:

President under whom the U.S. gave full recognition to Communist China.
(Answer: Jimmy Carter)

Pop Music:

Their grandfather had a number 1 record in 1935; their father, Number 1's in 1958 & 1961; and they hit number 1 in 1990.
(Answer: Gunnar & Matthew Nelson)

Before & After:

The “Jerry Maguire” star who automatically maintains your vehicle’s speed.
(Answer: Tom Cruise control)

Art History:

Unique quality of “First Communion of Anemic Young Girls in the Snow” shown at the 1883 Arts Incoherents Exhibit.

(Answer: all white)

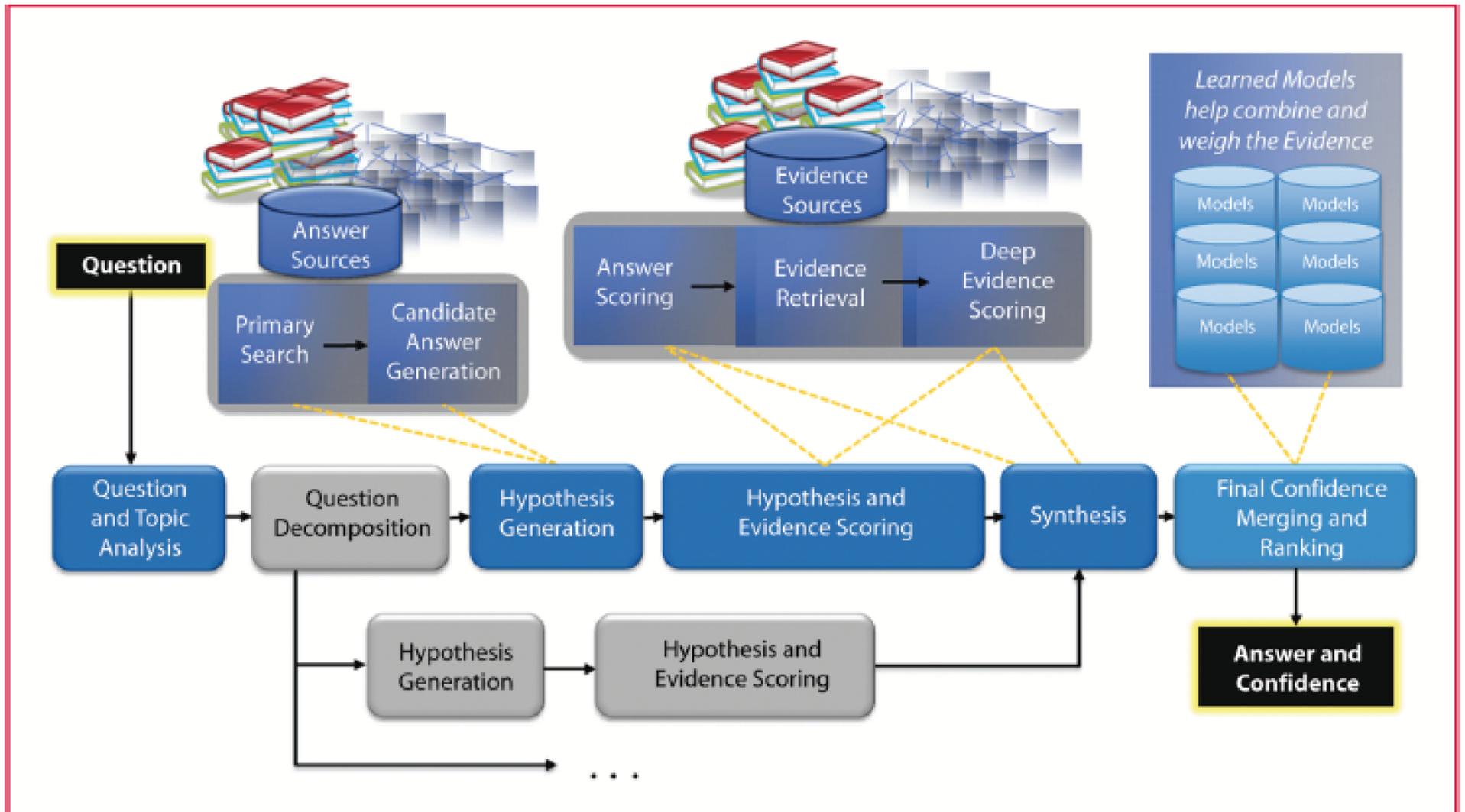
Common Bonds:

Feet, eyebrows and McDonald’s.
(Answer: arches)

Language:

The lead singer of the band Dengue Fever is from this country & often sings in Khmer.
(Answer: Cambodia)

Watson Deep QA Architecture



Watson's Data

- Not connected to the Internet during the game
- Stored approximately 4 terrabytes of data
- “Deep analytics” of text to extract relations and facts
 - Knowledge representation, primarily in the form of relations, both from relation extraction and semantic role labeling
- Processed 200 million pages of structured and unstructured data, including the entire Wikipedia
- Sources included encyclopedias, dictionaries, thesauri, newswire articles, and literary works
 - But only 2% of questions answered directly from structured data; all others used at least partly information from text

Watson's Steps

- Question Analysis: type of question and what the question is asking for
- Hypothesis generation by “thousands” of tasks
 - Quantity over accuracy
- Hypothesis and evidence scoring
 - Collects positive and negative evidence from passages
 - Uses relations between concepts learned from text:
 - Books have authors
 - Authors create characters
- Final merging and ranking
 - Uses past experience to weight types of evidence for different questions
 - Uses confidence of top answer to decide whether to “buzz in”
 - Wagering strategy

Information Search: Complex Questions

- Many questions go beyond asking for simple facts
 - Comparison questions
 - Questions that involve deeper understanding of issues
- These questions cannot typically be answered by a simple phrase or sentence
- Approaches focus on identifying an answer passage

Example Passage Retrieval System

- CNLP built a domain-specific QA system to support on-line aeronautics class
 - National Aeronautic & Space Agency funding
- Collection
 - **Textbooks, technical papers / reports, websites**
 - **Pre-selected for relevance and pedagogical value**
- Community of users focused on specific tasks
 - For undergrad students from 2 universities majoring in Aerospace Engineering
 - Students using system for a course can ask questions while working in teams or on own
- Where QA system must function:
 - In **real** time, not batch mode
 - On **real** users' **real** world questions
 - With **real**, not surrogate assessments of relevance
- Used in a collaborative learning environment

Sample Questions from Real Users

- *How difficult is it to mold and shape graphite-epoxies compared with alloys or ceramics that may be used for thermal protective applications?*
- *How does the shuttle fly?*
- *Do welding sites yield any structural weaknesses that could be a threat for failure?*
- *Are Thermal Protection systems of spacecrafts commonly composed of one panel or a collection of smaller tiles?*
- *How can the aerogels be used in insulation of holes in TPS?*
- **Two-stage QA model**
 - **1st – passage retrieval using expanded query representation**
 - **2nd – selection of answer-providing passages based on generic + specialized entities & relations**