



MAN VS. MACHINE

How IBM Built a *Jeopardy!* Champion

15.071x – The Analytics Edge

A Grand Challenge



- In 2004, IBM Vice President Charles Lickel and co-workers were having dinner at a restaurant
- All of a sudden, the restaurant fell silent
- Everyone was watching the game show *Jeopardy!* on the television in the bar
- A contestant, Ken Jennings, was setting the record for the longest winning streak of all time (75 days)

A Grand Challenge



- Why was everyone so interested?
 - *Jeopardy!* is a quiz show that asks complex and clever questions (puns, obscure facts, uncommon words)
 - Originally aired in 1964
 - A huge variety of topics
 - Generally viewed as an impressive feat to do well
- No computer system had ever been developed that could even come close to competing with humans on *Jeopardy!*

A Tradition of Challenges



- IBM Research strives to push the limits of science
 - Have a tradition of inspiring and difficult challenges
- Deep Blue – a computer to compete against the best human chess players
 - A task that people thought was restricted to human intelligence
- Blue Gene – a computer to map the human genome
 - A challenge for computer speed and performance

The Challenge Begins



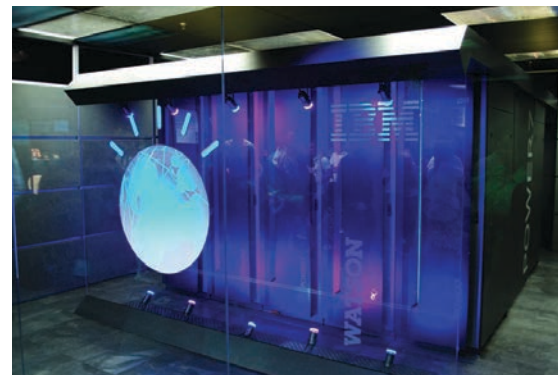
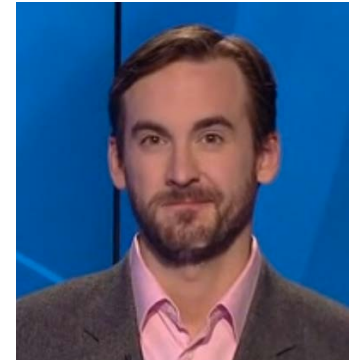
- In 2005, a team at IBM Research started creating a computer that could compete at *Jeopardy!*
 - No one knew how to beat humans, or if it was even possible
- Six years later, a two-game exhibition match aired on television
 - The winner would receive \$1,000,000

The Contestants

- Ken Jennings
 - Longest winning streak of 75 days
- Brad Rutter
 - Biggest money winner of over \$3.5 million
- Watson
 - A supercomputer with 3,000 processors and a database of 200 million pages of information



Image of Ken Jennings is in the public domain. Source: [Wikimedia Commons](#).



The Game of *Jeopardy!*

- Three rounds per game
 - Jeopardy
 - Double Jeopardy (dollar values doubled)
 - Final Jeopardy (wager on response to one question)
- Each round has five questions in six categories
 - Wide variety of topics (over 2,500 different categories)
- Each question has a dollar value – the first to buzz in and answer correctly wins the money
 - If they answer incorrectly they lose the money



Example Round



A Jeopardy! game board grid with 6 columns and 5 rows. The top row contains category names, and the subsequent rows contain monetary values. The categories are: THE DINOSAURS, NOTABLE WOMEN, OXFORD ENGLISH DICTIONARY, NAME THAT INSTRUMENT, BELGIUM, and COMPOSERS BY COUNTRY. The values are \$200, \$400, \$600, \$800, and \$1000.

| THE DINOSAURS | NOTABLE WOMEN | OXFORD ENGLISH DICTIONARY | NAME THAT INSTRUMENT | BELGIUM | COMPOSERS BY COUNTRY |
|---------------|---------------|---------------------------|----------------------|---------|----------------------|
| \$200 | \$200 | \$200 | \$200 | \$200 | \$200 |
| \$400 | \$400 | \$400 | \$400 | \$400 | \$400 |
| \$600 | \$600 | \$600 | \$600 | \$600 | \$600 |
| \$800 | \$800 | \$800 | \$800 | \$800 | \$800 |
| \$1000 | \$1000 | \$1000 | \$1000 | \$1000 | \$1000 |

Jeopardy! Questions

- Cryptic definitions of categories and clues
- Answer in the form of a question
 - Q: Mozart's last and perhaps most powerful symphony shares its name with this planet.
 - A: What is Jupiter?
 - Q: Smaller than only Greenland, it's the world's second-largest island.
 - A: What is New Guinea?

Why is Jeopardy Hard?

- Wide variety of categories, purposely made cryptic
- Computers can easily answer precise questions
 - What is the square root of $(35672-183)/33$?
- Understanding natural language is hard
 - Where was Albert Einstein born?
 - Suppose you have the following information:
“One day, from his city views of Ulm, Otto chose a water color to send to Albert Einstein as a remembrance of his birthplace.”
 - Ulm? Otto?

A Straightforward Approach



- Let's just store answers to all possible questions
- This would be impossible
 - An analysis of 200,000 previous questions yielded over 2,500 different categories
- Let's just search Google
 - No links to the outside world permitted
 - It can take considerable skill to find the right webpage with the right information

Using Analytics



- Watson received each question in text form
 - Normally, players see and hear the questions
- IBM used analytics to make Watson a competitive player
- Used over 100 different techniques for analyzing natural language, finding hypotheses, and ranking hypotheses

Watson's Database and Tools

- A massive number of data sources
 - Encyclopedias, texts, manuals, magazines, Wikipedia, etc.
- Lexicon
 - Describes the relationship between different words
 - Ex: “Water” is a “clear liquid” but not all “clear liquids” are “water”
- Part of speech tagger and parser
 - Identifies functions of words in text
 - Ex: “Race” can be a verb or a noun
 - He won the race by 10 seconds.
 - Please indicate your race.

How Watson Works



- Step 1: Question Analysis
 - Figure out what the question is looking for
- Step 2: Hypothesis Generation
 - Search information sources for possible answers
- Step 3: Scoring Hypotheses
 - Compute confidence levels for each answer
- Step 4: Final Ranking
 - Look for a highly supported answer

Step 1: Question Analysis



- What is the question looking for?
- Trying to find the Lexical Answer Type (LAT) of the question
 - Word or noun in the question that specifies the type of answer
- Ex: “Mozart’s last and perhaps most powerful symphony shares its name with **this planet.**”
- Ex: “Smaller than only Greenland, **it’s** the world’s second-largest island.”

Step 1: Question Analysis



- If we know the LAT, we know what to look for
- In an analysis of 20,000 questions
 - 2,500 distinct LATs were found
 - 12% of the questions do not have an explicit LAT
 - The most frequent 200 explicit LATs cover less than 50% of the questions
- Also performs **relation detection** to find relationships among words, and **decomposition** to split the question into different clues

Step 2: Hypothesis Generation



- Uses the question analysis from Step 1 to produce candidate answers by searching the databases
- Several hundred candidate answers are generated
- Ex: “Mozart’s last and perhaps most powerful symphony shares its name with **this planet.**”
 - Candidate answers: Mercury, Earth, Jupiter, etc.

Step 2: Hypothesis Generation

- Then each candidate answer plugged back into the question in place of the LAT is considered a hypothesis
 - Hypothesis 1: “Mozart’s last and perhaps most powerful symphony shares its name with **Mercury**.”
 - Hypothesis 2: “Mozart’s last and perhaps most powerful symphony shares its name with **Jupiter**.”
 - Hypothesis 3: “Mozart’s last and perhaps most powerful symphony shares its name with **Earth**.”

Step 2: Hypothesis Generation



- If the correct answer is not generated at this stage, Watson has no hope of getting the question right
- This step errors on the side of generating a lot of hypotheses, and leaves it up to the next step to find the correct answer

Step 3: Scoring Hypotheses



- Compute *confidence levels* for each possible answer
 - Need to accurately estimate the probability of a proposed answer being correct
 - Watson will only buzz in if a confidence level is above a threshold
- Combines a large number of different methods

Lightweight Scoring Algorithms

- Starts with “lightweight scoring algorithms” to prune down large set of hypotheses
- Ex: What is the likelihood that a candidate answer is an instance of the LAT?
 - If this likelihood is not very high, throw away the hypothesis
- Candidate answers that pass this step proceed the next stage
 - Watson lets about 100 candidates pass into the next stage

Scoring Analytics

- Need to gather supporting evidence for each candidate answer
- Passage Search
 - Retrieve passages that contain the hypothesis text
 - Let's see what happens when we search for our hypotheses on Google
 - Hypothesis 1: “Mozart’s last and perhaps most powerful symphony shares its name with **Mercury**.”
 - Hypothesis 2: “Mozart’s last and perhaps most powerful symphony shares its name with **Jupiter**.”

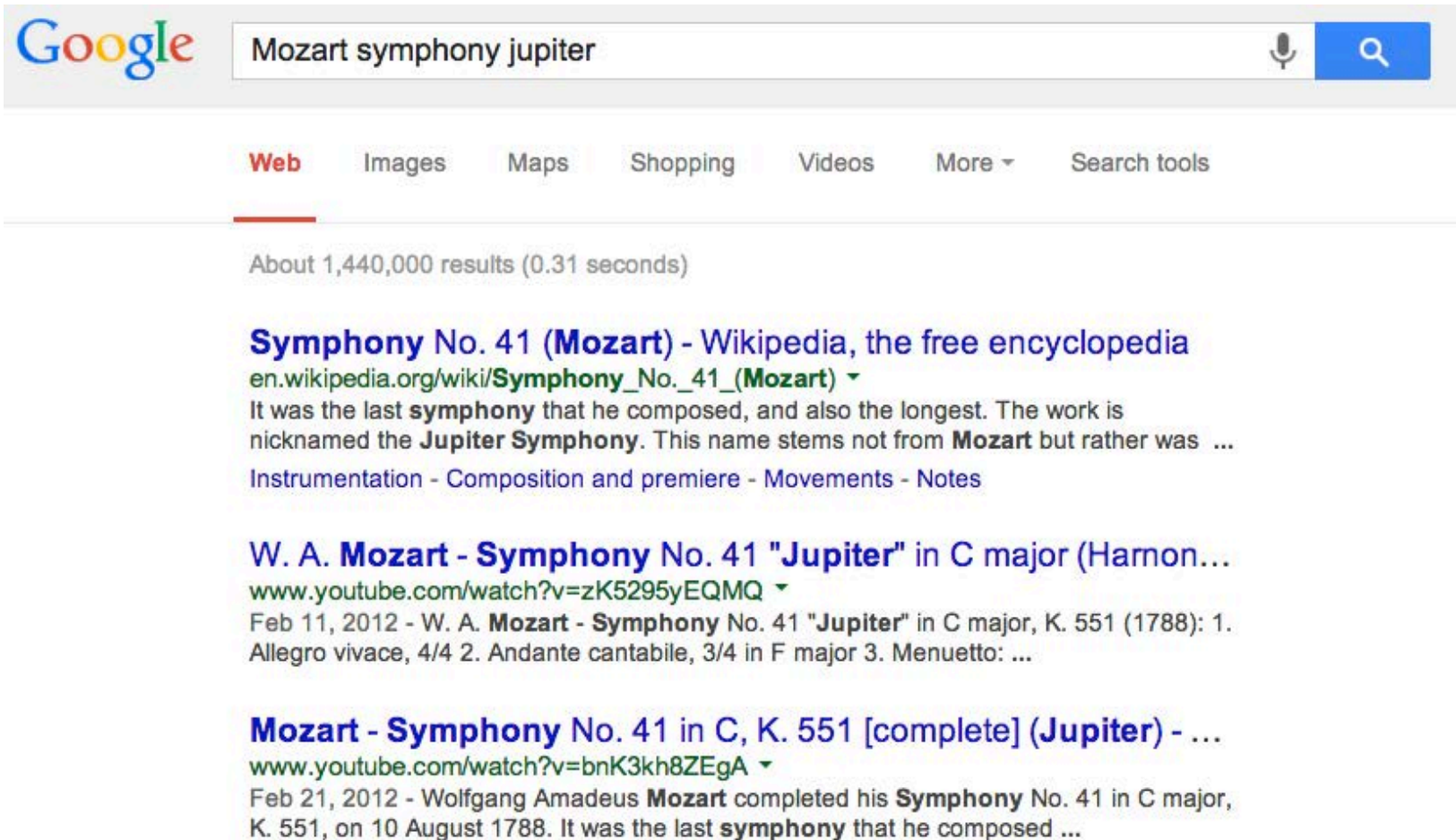
Passage Search



The image shows a Google search interface. The search bar contains the text "Mozart symphony mercury". Below the search bar, there are navigation tabs for "Web", "Images", "Maps", "Shopping", "News", "More", and "Search tools". The "Web" tab is selected. Below the tabs, it says "About 938,000 results (0.55 seconds)". There are three search results listed:

- Mercury: Mozart's Jupiter Symphony - The Front Row**
www.thefrontrow.org/.../1349112026-Mercury-Mozarts-Jupiter-Sympho...
Oct 1, 2012 - Antoine Plante, artistic director of the period-instruments group **Mercury** - The Orchestra Redefined, talks about the program of **symphonies** and ...
- Mozarts Jupiter Symphony | Mercury (formerly Mercury Baro...**
www.artshound.com › MUSIC
Opening the **Mercury** season at the Wortham Center's Cullen Theatre on Saturday, October 6, 2012 will be a program featuring **Mozart's** "Jupiter" **Symphony**.
- Event - Mozart's "Jupiter" Symphony Mercury Houston - The ...**
mercuryhouston.org/events/7/
Mercury combines the forces of Haydn and **Mozart** for a memorable concert event, highlighted by **Mozarts** iconic Jupiter **Symphony**. A wonderful way to kick off ...

Passage Search



The image shows a Google search interface. The search bar contains the text "Mozart symphony jupiter". Below the search bar, there are navigation tabs for "Web", "Images", "Maps", "Shopping", "Videos", "More", and "Search tools". The "Web" tab is selected. Below the tabs, it says "About 1,440,000 results (0.31 seconds)". There are three search results listed:

- Symphony No. 41 (Mozart) - Wikipedia, the free encyclopedia**
[en.wikipedia.org/wiki/Symphony_No._41_\(Mozart\)](https://en.wikipedia.org/wiki/Symphony_No._41_(Mozart))
It was the last **symphony** that he composed, and also the longest. The work is nicknamed the **Jupiter Symphony**. This name stems not from **Mozart** but rather was ...
Instrumentation - Composition and premiere - Movements - Notes
- W. A. Mozart - Symphony No. 41 "Jupiter" in C major (Hamon...**
www.youtube.com/watch?v=zK5295yEQMQ
Feb 11, 2012 - W. A. **Mozart** - **Symphony** No. 41 "**Jupiter**" in C major, K. 551 (1788): 1. Allegro vivace, 4/4 2. Andante cantabile, 3/4 in F major 3. Menuetto: ...
- Mozart - Symphony No. 41 in C, K. 551 [complete] (Jupiter) - ...**
www.youtube.com/watch?v=bnK3kh8ZEgA
Feb 21, 2012 - Wolfgang Amadeus **Mozart** completed his **Symphony** No. 41 in C major, K. 551, on 10 August 1788. It was the last **symphony** that he composed ...

Scoring Analytics



- Determine the degree of certainty that the evidence supports the candidate answers
- More than 50 different scoring components
- Ex: Temporal relationships
 - “In 1594, he took a job as a tax collector in Andalusia”
 - Two candidate answers: Thoreau and Cervantes
 - Thoreau was not born until 1817, so we are more confident about Cervantes

Step 4: Final Merging and Ranking



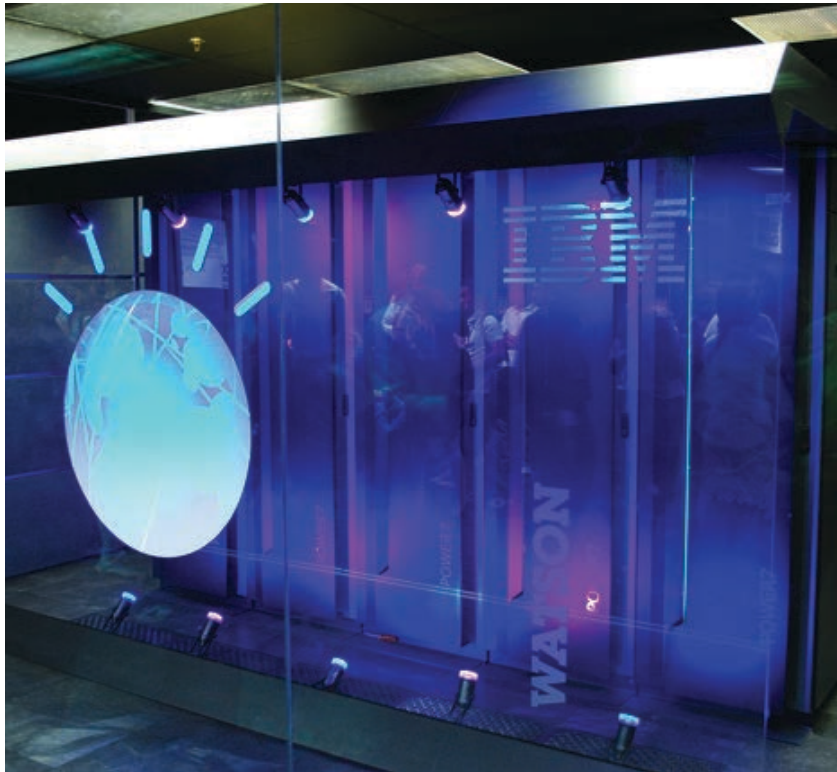
- Selecting the single best supported hypothesis
- First need to merge similar answers
 - Multiple candidate answers may be equivalent
 - Ex: “Abraham Lincoln” and “Honest Abe”
 - Combine scores
- Rank the hypotheses and estimate confidence
 - Use predictive analytics

Ranking and Confidence Estimation



- Training data is a set of historical *Jeopardy!* questions
- Each of the scoring algorithms is an independent variable
- Use logistic regression to predict whether or not a candidate answer is correct, using the scores
- If the confidence for the best answer is high enough, Watson buzzes in to answer the question

The Watson System



- Eight refrigerator-sized cabinets
- High speed local storage for all information
- Originally took over two hours to answer one question
 - This had to be reduced to 2-6 seconds

Let the games begin!



- The games were scheduled for February 2011
- Two games were played, and the winner would be the contestant with the highest winnings over the two games

The Results

| | Ken Jennings | Brad Rutter | Watson |
|---------------|---------------------|--------------------|-----------------|
| Game 1 | \$4,800 | \$10,400 | \$35,734 |
| Game 2 | \$19,200 | \$11,200 | \$41,413 |
| Total | \$24,000 | \$21,600 | \$77,147 |

What's Next for Watson



- Apply to other domains
 - Watson is ideally suited to answering questions which cover a wide range of material and often have to deal with inconsistent or incomplete information
- Medicine
 - The amount of medical information available is doubling every 5 years and a lot of the data is unstructured
 - Cancer diagnosis and selecting the best course of treatment
 - MD Anderson and Memorial Sloan-Kettering Cancer Centers

The Analytics Edge



- Combine many algorithms to increase accuracy and confidence
 - Any one algorithm wouldn't have worked
- Approach the problem in a different way than how a human does
 - Hypothesis generation
- Deal with massive amounts of data, often in unstructured form
 - 90% of data is unstructured

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