Todai Robot Project
Can a machine solve university entrance exam problems automatically?

Noriko H. Arai
National Institute of Informatics
Todai Robot Project

Pursue a real breakthrough by challenging a real intellectual task through the reunion of the AI achievements in the past 30 years

Milestones

2016 – Mark a high score in the National Center Test
   – “Comprehension & Thinking”
     - Computer algebra (Quantifier elimination of RCF problems)
     - Factoid
     - Textual entailment recognition, ...

2021 – Pass the entrance exam of the University of Tokyo
   – “Comprehension, Thinking & Answer generation”
     - Document summarization,
     - Deep and precise language processing,
     - Machine translation,
     - Software component integration framework, ...
University entrance exams in Japan

**National Center Test** (multiple choice) 7 subjects
- Mathematics (Introductory, Advanced)
- Natural Science (Physics, Chemistry, Biology, Earth Science)
- Social Studies (World History, Japanese History, Economics & Politics, Ethics, Geography)
- English

---

Tokyo University
Second Stage Exam (written test)
- Mathematics
- 2 × Natural Science or 2 × Social Science
- Japanese
- English
MOZART'S LAST & PERHAPS MOST POWERFUL SYMPHONY SHARES ITS NAME WITH THIS PLANET
Symphony No. 41 (Mozart)

From Wikipedia, the free encyclopedia

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, and also the longest.

The work is nicknamed the Jupiter Symphony. This name stems not from Mozart but rather was likely coined by the impresario Johann Peter Salomon in an early arrangement for piano.
20 years exam data
Dictionaries
Wikipedia JA...
“A Pendulum Swung Too Far” (Ken Church, ACL-2011)

DARPA AI Projects (2010～)

**Todai Robot Project** (2011～): NII

Project ARISTO (2013～): Allen Institute for AI

---

Integration of Underlying Technologies

Modern Hybrid of Logical and Statistical Approaches
Technology integration & Improvement
- Integration of elemental technologies
- Language understanding boosted by domain knowledge and inference
- Co-reference & zero anaphora resolution

Basic technologies for Center Tests
- Syntactic parsing
- Textual entailment recognition
- Physical simulation platform
- Semantic language design
- Semantic analysis

Start 2011

Data building
Problem analysis

Development of a UIMA platform
Management of international evaluation tasks

Technologies for secondary exams
- Text summarization
- Meta-knowledge structure recognition
- Undecidable math problems
- Image and NLP
- Qualitative reasoning

Mathematica, Watson, Tsubaki, SyNRAC...

Development
Evaluation
We're here now!
Choose the correct statement about military systems.

1. The Janissaries were standing troops in the Ottoman Empire.
2. The Frankish Kingdom established the thema system.

Janissary
... The Janissaries were infantry Musketeer units that formed the Ottoman sultan’s household troops and bodyguards. The force was created by the Sultan Murad I from Christian boys ...

Theme (Byzantine district)
... The themes or themata were the main administrative divisions of the middle Byzantine Empire.
Q. Select a correct statement from 1)-3):

1) The Eight Banners was an army founded by the Shunzhi Emperor.
2) The Janissaries were the standing army of the Ottoman Empire.
3) In Francia, a system of farmer-soldiers was established under the theme system (system of military districts).

**Accurate entailment recognition by logic/statistics hybrid system**

- Expressive & efficient meaning representation by algebraic forms with set operators
- Inference by logical operation and machine learning

**ACL 2014**

"Logical inference on dependency-based compositional semantics"

**Evaluation tasks in NTCIR-11**

<table>
<thead>
<tr>
<th>System</th>
<th>Points (/100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shizuoka U.</td>
<td>57</td>
</tr>
<tr>
<td>CMU1</td>
<td>55</td>
</tr>
<tr>
<td>CMU2</td>
<td>52</td>
</tr>
<tr>
<td>CMU3</td>
<td>48</td>
</tr>
<tr>
<td>YNU</td>
<td>46</td>
</tr>
<tr>
<td>CMU4</td>
<td>45</td>
</tr>
<tr>
<td>CMU5</td>
<td>43</td>
</tr>
<tr>
<td>Fujitsu Lab</td>
<td>41</td>
</tr>
<tr>
<td>Fujitsu R&amp;D</td>
<td>37</td>
</tr>
<tr>
<td>Fujitsu Lab2</td>
<td>34</td>
</tr>
<tr>
<td>Hokkkaido U.</td>
<td>31</td>
</tr>
<tr>
<td>Fujitsu Lab3</td>
<td>23</td>
</tr>
<tr>
<td>Baseline</td>
<td>20</td>
</tr>
</tbody>
</table>
• By combining the three strategies, it became possible to solve the various questions.
Example) Using Question Answering

- Converting the choice to the factoid question
  - “Charlemagne defeats the Magyar at the 8th century.” (false choice)
  - → “Charlemagne defeats (PersonType) at the 8th century.” → ?

Search Results in textbooks and Wikipedia

... At the end of the 8th century, the Avars that had dominated this land was subsumption to the Frank kingdom under attack of Charlemagne. ... (Wikipedia)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Word</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Avars</td>
<td>3.2</td>
</tr>
<tr>
<td>2</td>
<td>Mongolian</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>5</td>
<td>Magyar</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Actually, “Avars” is correct

Distance = 14 words
Convert the distance to the score
Calculate the difference from the first place as the cost
Cost of “Magyar” is 3.2 – 1.1 = 2.1

The score in 2015: 76
How about mathematics?
Let $l$ be the trajectory of $(t + 2, t + 2, t)$ for $t$ ranging over $\mathbb{R}$.

$O(0, 0, 0), A(2, 1, 0)$, and $B(1, 2, 0)$ are on a sphere, $S$, centered at $C(a, b, c)$.

Determine the condition on $a, b, c$ for which $S$ intersects with $l$.

(Hokkaido Univ. 2011)
Let \( l \) be the trajectory of \((t + 2, t + 2, t)\) for \( t \) ranging over \( \mathbb{R} \).

\( O(0, 0, 0), A(2, 1, 0), \) and \( B(1, 2, 0) \) are on a sphere, \( S \), centered at \( C(a, b, c) \).

Determine the condition on \( a, b, c \) for which \( S \) intersects with \( l \).

\[ \left\{ \begin{array}{l}
    a^2 + b^2 = r^2 \\
    (2 - a)^2 + (1 - b)^2 = r^2 \\
    (1 - a)^2 + (2 - b)^2 = r^2 \\
    x = t + 2 \\
    y = t + 2 \\
    z = t \\
    x^2 + y^2 + z^2 - \frac{5}{3}x - \frac{5}{3}y - 2cz = 0
\end{array} \right. \]

\( 6a = 5 \land 6b = 5 \land (3c \leq 1 \lor 13 \leq 3c) \)
Let \( l \) be the trajectory of \((t + 2, t + 2, t)\) for \( t \) ranging over \( \mathbb{R} \).

\( O(0, 0, 0), A(2, 1, 0), \) and \( B(1, 2, 0) \) are on a sphere, \( S \), centered at \( C(a, b, c) \).

Determine the condition on \( a, b, c \) for which \( S \) intersects with \( l \).

(Hokkaido Univ. 2011)

\[
\exists l \exists u \exists v \exists R (l = \text{line}(u, v) \land \forall p(p \in l \iff \exists t(p = (t + 2, t + 2, t))) \land S = \text{sphere}((a, b, c), R) \land (0, 0, 0) \in S \land (2, 1, 0) \in S \land (1, 2, 0) \in S \land \exists q(\text{intersect}(S, l, q)))
\]

\[
\exists u_x \exists u_y \exists u_z (((-u_x = 0)) \lor (-u_y = 0)) \lor (-u_z = 0)) \land (\exists v_x \exists v_y \exists v_z (u_x v_y - v_x b^2 + (u_x v_z + v_x c^2 - R^2)) \land (0 < R) \land (a^2 + b^2 + c^2 \land ((2 - a)^2 + (1 - b)^2 + c^2 = R^2))) \land (\exists v_x \exists v_y (((0 = u_y v_z - v_z))) \land (0 = u_z (v_z - v_y) - u_y (v_z - v_x))) \land (0 = u_x (v_x - v_z) - u_z (v_x - v_y))) \land ((p_x = p_z + 2) \land (p_y = p_z + 2)) \lor (\forall t_2 ((-p_x = t_2 u_x + v_x)) \lor (-p_y = t_2 u_y + v_y))) \land (\forall t_3 (t_3 = (t_3 u_z + v_z) \land (p_z + 2 = t_3))) \land (\exists u_x \exists u_y (((-u_x = 0)) \lor (-u_y = 0)) \lor (-u_z = 0)) ) \land (0 = u_y u_z - u_z u_y) \land (0 = u_x u_z - u_z u_x)) \land (0 = u_x u_y - u_y u_x))
\]

\[6a = 5 \land 6b = 5 \land (3c \leq 1 \lor 13 \leq 3c)\]
Is it possible to determine the local theory just from wordings?

• Let $O$ be a circle of radius 1 centered on the origin. Given points $A$ and $B$ on the circumference of $O$, find the point on the x-axis equidistant from $A$ and $B$.

  $\in RCF$

• Let $O$ be a circle of radius 1 centered on the origin. Find a point $A$ on the x-axis such that the distance from point $A$ to the origin is equal to the length of the circumference of $O$.

  $\notin RCF$
C is a circle that passes through the origin and (1, 1).

(1) Find the radius of C when C is tangent to the x-axis.

(2) Find the minimum diameter of C.
Tokyo Univ. prep test (Math, 2013)

Mathematics (humanities)
Av. = 57.4
Our system = 59.4

Mathematics (sciences)
Av. = 59.4
Our system = 61.2
Todai Robot marked higher than human examinee in Mathematics (Introductory, Advanced), Japanese History and World History. Need more improvements in Physics, Japanese and English.
2016 Center Mock Test Result

We're here now!
# University of Tokyo: Mock Test Results on World History

<table>
<thead>
<tr>
<th></th>
<th>I 600 words Essay on “Changes of state systems of Western Europe and Asian countries from 16 to 18 centuries”</th>
<th>II Short essays (60-90 words)</th>
<th>III Factoid questions</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average</strong></td>
<td>4.3</td>
<td>6.5</td>
<td>6.4</td>
<td>17.2</td>
</tr>
<tr>
<td><strong>Todai Robot</strong></td>
<td>9</td>
<td>0</td>
<td>5</td>
<td>21</td>
</tr>
<tr>
<td><strong>T-Score</strong></td>
<td>61.8</td>
<td>35.6</td>
<td>43.9</td>
<td>54.1</td>
</tr>
</tbody>
</table>
Is there any university our system can enter?

Evaluation of our system in National Center prep test (2015)

<table>
<thead>
<tr>
<th></th>
<th>Number of Universities and Departments</th>
<th>Universities which our system can enter with a probability of more than 80%</th>
</tr>
</thead>
<tbody>
<tr>
<td>National universities</td>
<td>170 universities, 570 departments</td>
<td>33 university, 39 departments</td>
</tr>
<tr>
<td>Private universities</td>
<td>580 universities, 1723 departments</td>
<td>441 universities, 1055 departments</td>
</tr>
<tr>
<td>Total</td>
<td>750 universities, 2293 departments</td>
<td>474 universities, 1094 departments</td>
</tr>
</tbody>
</table>

Our system possibly enters more than half universities (more than 3/4 private universities) in Japan!
Can a Robot Get Into Japan’s Most Prestigious University?

Tokyo University’s notoriously difficult entrance exam shatters the dreams of thousands of Japanese high school students each year. Can it also crush the hopes of Japan’s best robot scientists?

The scientists won’t be taking the test themselves. Instead, this being Japan, researchers have posed the question of whether a robot could pass the test to get into the country’s most prestigious university.

Fujitsu Ltd. is betting artificial intelligence is smart enough to make the grade for Todai — as the university is also known. In response to the challenge “Can a Robot Pass the Todai Entrance Exam?”, the electronics company said Monday that its research subsidiary, Fujitsu Laboratories Ltd. will join forces with Japan’s National Institute of Informatics, National Institute of Technology, Sendai.

Can an AI Get Into the University of Tokyo?

The school’s notorious entrance exam could be the perfect test for artificial intelligence

For the thousands of secondary school students who take Japan’s university entrance exams each year, test days are long-dreaded nightmares of jitters and sweaty palms. But the newest test taker can be counted on to keep its cool: AIs don’t sweat.

At Japan’s National Institute of Informatics (NII), in Tokyo, a research team is trying to create an AI that can take the exam by providing a mock test, called “Enki-exam.” The researchers used data from six university entrance exams in 2011-2016 to train the machine and are expected to make it available to universities for testing this year.

NHK Special
“Computer Revolution: Emergence of the most powerful computers ever ”
NHK News 7 (prime time news)
BS Nihon TV (40min news Show)
Thank you.