Engineering a Robot to Solve a Rubik's Cube

Ruku the Robot and more…

Newport County Radio Club
PI day 3.14.16

Paul Fredette, K1YBE

What we did for STEM for Girls..
Umass Dartmouth - Kaput Center Event 2015

- Engineering versus Science

  "Scientists investigate that which already is; engineers create that which has never been."

  \- Albert Einstein

- History of some women in
  - **S***cience*
  - **T***echnology*
  - **E***ngineering*
  - **M***ath*
- Teams prepare to Solve Rubik's cube
- Using the RUKU the Robot
- Engineering a "better" robot

Workshop Team

Kaput Center University of Mass - Dartmouth

Paul Fredette -- pfredette@promptus.co

RUKU Design – University of California – San Diego

PROCESS TO SOLVE THE RUBIK's CUBE

A
- CUBE FACTS
- CUBE OPERATIONS

B
- INITIAL CUBE
- CUBE SOLUTION

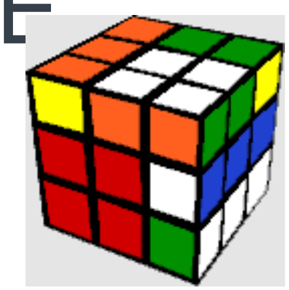
C
- ROBOT OPERATION

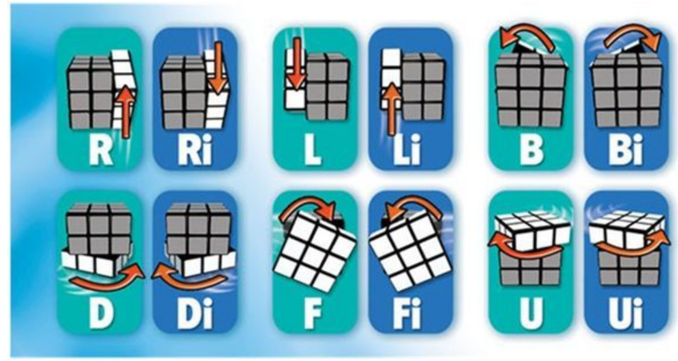
› Know the problem

› Do the work

› Enjoy the solution

Know Your CUBE





CUBE FACTS

- Best Selling Toy in the U.S.
- Ernõ Rubik patented it in 1975 but didn't know if a solution existed.
- 43,252,003,274,489,856,000 (43 quintillion combinations)

  $= 8! \times 3^7 \times (12!/2) \times 2^{11}$
- Center squares don't move
- Color pairs are: Blue/Green, White/Yellow, Orange/Red

CUBE SOLUTION

- Same color for all the squares on each sid
- Moves are rotations of the sides:
  - *F* (Front): the side currently facing the solve
  - *B* (Back): the side opposite the front
  - *U* (Up): the side above or on top of the front side
  - *D* (Down): the side opposite the top, underneath the Cube
  - *L* (Left): the side directly to the left of the front
  - *R* (Right): the side directly to the right of the front
  - Called "David Singmaster Notation"

$$\frac{12! * 2^{12} * 8! * 3^{8}}{3 * 2 * 2}$$

= 43,252,003,274,489,856,000

Quintillion

Quadrillion

Trillion

Billion

Million

Thousand

MATH -- Permutations

- The original (3×3×3) Rubik's Cube has eight corners and twelve edges. There are 8! (40,320) ways to arrange the corner cubes.
- Seven can be oriented independently, and the orientation of the eighth depends on the preceding seven, giving 3^7 (2,187) possibilities.
- There are 12!/2 (239,500,800) ways to arrange the edges, since an even permutation of the corners implies an even permutation of the edges as well.
- When arrangements of centers are also permitted, as described below, the rule is that the combined arrangement of corners, edges, and centers must be an even permutation.) Eleven edges can be flipped independently, with the flip of the twelfth depending on the preceding ones, giving 2^{11} (2,048) possibilities.

Initial Cube Permutations: (43 quintillion combinations)

$$43{,}252{,}003{,}274{,}489{,}856{,}000 = 8! \text{ X } 3^7 \text{ x}(12!/2) \text{ x } 2^{11}$$

$8! = 8 * 7 * 6 * 5 * 4 * 3 * 2 * 1 = 40320$

$$3^7 = 3 \text{ x } 3 \text{ x } 3 \text{ x } 3 \text{ x } 3 \text{ x } 3 \text{ x } 3 = 2187$$

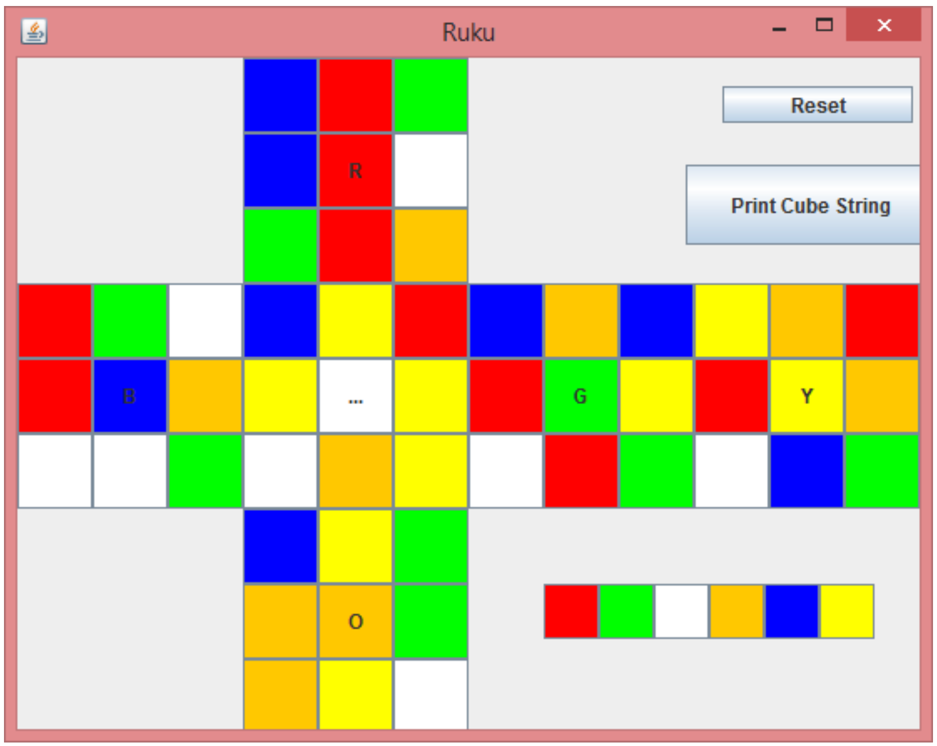
$$2^{11} = 2 \text{ x } 2 \text{ x } 2 \text{ x } 2 \text{ x} 2 \text{ x } 2 \text{ x } 2 \text{ x } 2 \text{ x } 2 \text{ x } 2 \text{ x } 2 = 2048$$

$$12! = 12 \text{ x } 11 \text{ x } 10 \text{ x } 9 \text{ x } 8! = 479{,}001{,}600$$

Counting the Permutations of the Rubik's Cube, Scott Vaughen. Professor of Mathematics. Miami Dade College.

Step 1. Enter initial state Manual entry program

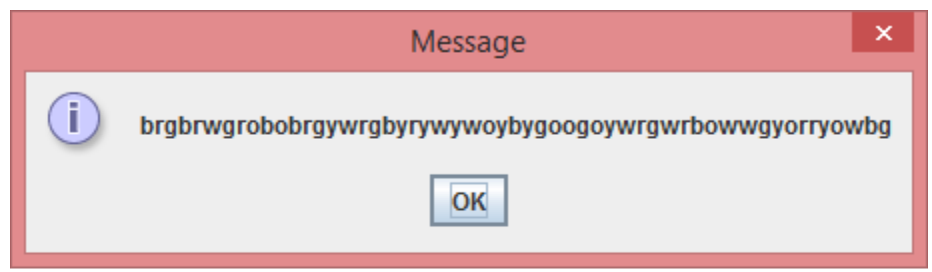
INITIAL CUBE



START RASPBERRY PI COMMAND WINDOW

Use Ruku.java program to generate the cube state

```
>cd Desktop
>cd ExtractedFiles
>sudo -s
>java Ruku
```

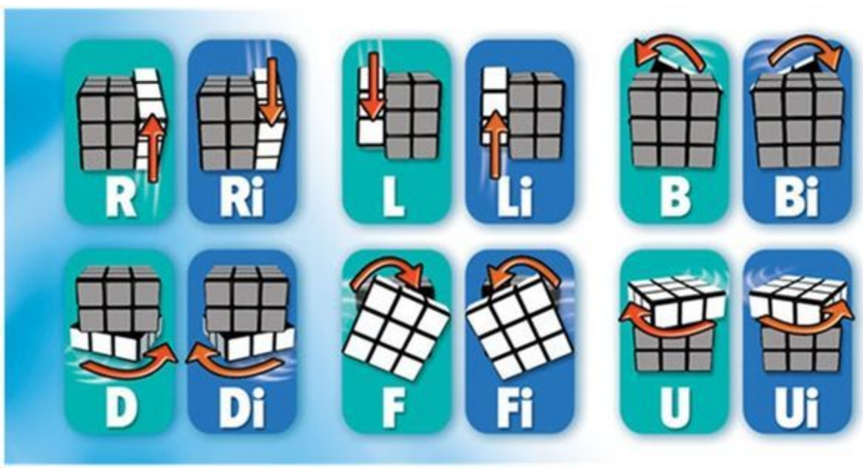


brgbrwgrobobrgywrgbyrywywoybygoogoywrgwrbowwgyorryowbg

Step 2. Find the solution
< 20 operations

STEPS

OPERATIONS




```
#cd Solver
#./RukuSolverRP1 “initial state”
solution1
#python fixSolution.py “solution1
solution2
```

Insert Cube.. Align 4 colors plus red on to

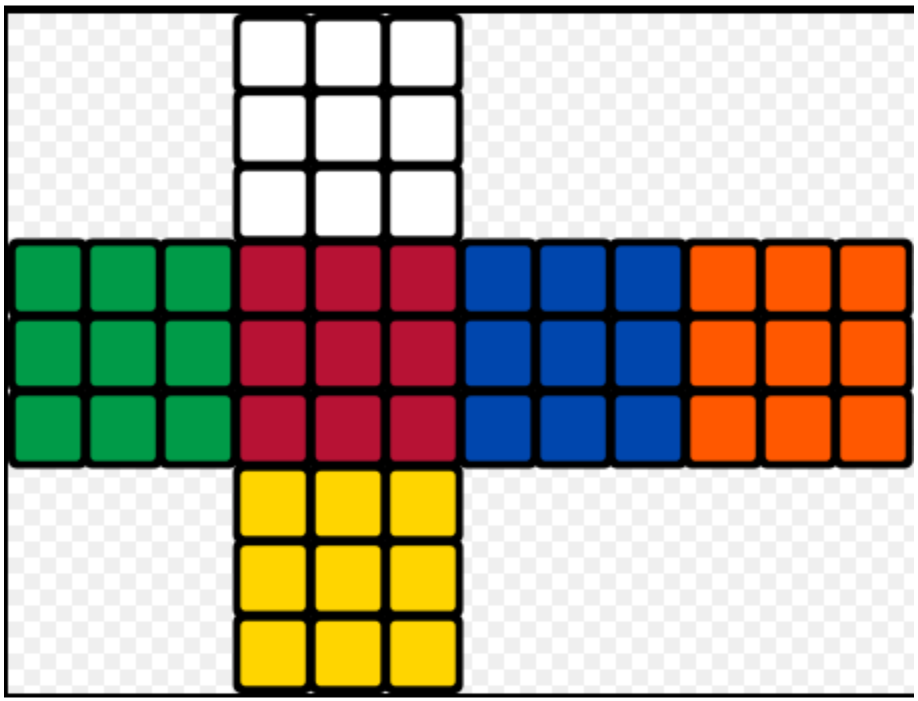
```
#python Rukupython0.py “zero”
#python Rukupython0.py “test” 0
#Python Rukupython0.py 7 “solutio
```

IN LINUX, YOU CAN COMBINE LINES 2 AND 3 AS FOLLOWS:

```
#python fixSolution.py $(#./RukuSolverRP1 “initial state”)
```

SOLVE THE PROBLEM

FINAL CUBE



CUBE OPERATIONS

STEPS

- Confuser mixes up cube
- Team 1 Open GUI program to enter cube
- Team 2 fills in form and enters string with text editor
- Each QA checker verifies string against cube with Reader
- SOLVER finds Solution String
- Robot operator puts cube in Robot
- QA checker
- Confuser times how long ROBOT moves cube to Final Solution

PROGRAM OPERATION

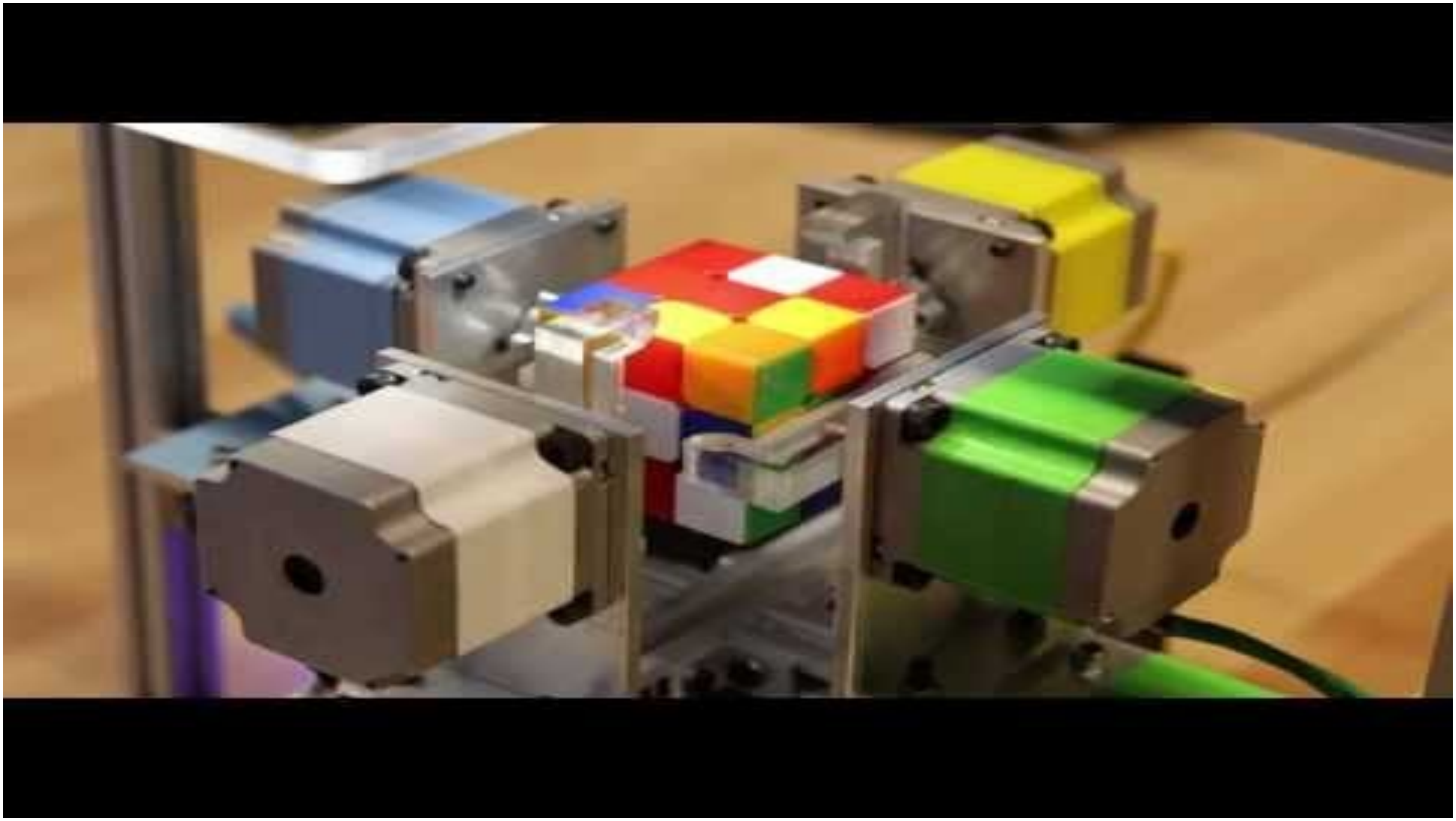
- ****************** Ruku Java ********************
- Use Ruku.java to help generate the cube string.
- **`javac Ruku.java && java Ruku`**
- will compile and run this.
- Example in Windows.
- C:\Program Files\Java\jdk1.8.0_45\bin>javac Ruku.java
- C:\Program Files\Java\jdk1.8.0_45\bin>java Ruku
- sides:{W=byrywywoy, G=bobrgywrg, R=brgbrwgro, O=bygoogoyw, Y=yorryowbg, B=rgwrbowwg}
- finalstring: brgbrwgrobobrgywrgbyrywywoybygoogoywrgwrbowwgyorryowbg
- sides:{W=byrywywoy, G=bobrgywrg, R=brgbrwgro, O=bygoogoyw, Y=yorryowbg, B=rgwrbowwg}
- **finalstring: brgbrwgrobobrgywrgbyrywywoybygoogoywrgwrbowwgyorryowbg**
- ****************** RukuSolver ********************
- run RukuSolver using
- **`./RukuSolver "grrorrybbrbyggybogowwwwowoyrwyogorrrygbbogbbbyygyowgw"`**
- This will output the solution:
- R D' F L' U' D' L' U' R' D2 L D B2 D' L2 D' B2 R2 D2 L2 D2
- Which can be given to the RukuPython Script that controls the motors like this:
- ****************** RukuPython0.py ********************
- **`python RukuPython0.py "R D' F L' U' D' L' U' R' D2 L D B2 D' L2 D' B2 R2 D2 L2 D2"`**
- Be sure to run RukuPython0.py as the root user.
- The command sudo -s can do this for you.

Engineering a “better” robot

- What do you think would make a better robot?
  - Faster
  - Smaller
  - More energy efficient
  - Lighter
  - Stronger
  - ??
- The engineer's first problem in any design situation is to discover what the problem really is. -Sir Henry Royce
- Engineers use the term “Trade Offs” to compare benefits with costs

RUKU FACTS and “TRADE OFFs”

Design item	Ruku	Options
People/Goals	US San Diego Students / Education	Designers / Profit
Parts	Brackets (Plastic/Aluminum) Motors (6 Stepper motors) Frame (Aluminum) Computer (Raspberry PI or PI2)	Wood/Steel/other plastics Servo, Fluids (Air/Hydraulic) Wood Arduino
Cost	Target $99, Initial $200	Lego: Mindstorms $350
Design	Programming: Python, Java Motor Control: Special Circuit Power : 5V and 12V Solution Method (MATH) Colors, Stickers, Size	C, C++ Buy a standard one Based on use / Efficiency Number of moves
Manufacturing	Brackets 3D Printed Manually assembled and tested	Moulded/Machined Many options
Marketing	Kickstarter (Failed initially) Advertising (Today)	Investors Word of mouth
Documentation	Videos, Readme file	Manual, Videos, Web



REFERENCES AND CREDITS

How to Solve a Rubik's Cube, Guide for Beginners

http://www.rubiksplace.com/

http://www.instructables.com/id/How-To-Solve-The-Rubiks-Cube-1/

15 min video:
http://www.instructables.com/id/Solve-a-Rubiks-Cube-EASY/

Non-human solving:

The fastest non-human time for a physical 3×3×3 Rubik's Cube is 3.25 seconds, set by CubeStormer III, a robot built using Lego Mindstorms and a Samsung Galaxy S4.[64]

This beats the prior 5.27 seconds, set by CubeStormer II, a robot built using Lego Mindstorms and a Samsung Galaxy S2.[65] This had in turn broken the previous record of 10.69 seconds, achieved by final year computing students at Swinburne University of Technology in Melbourne, Australia in 2011.[66]

Solution history

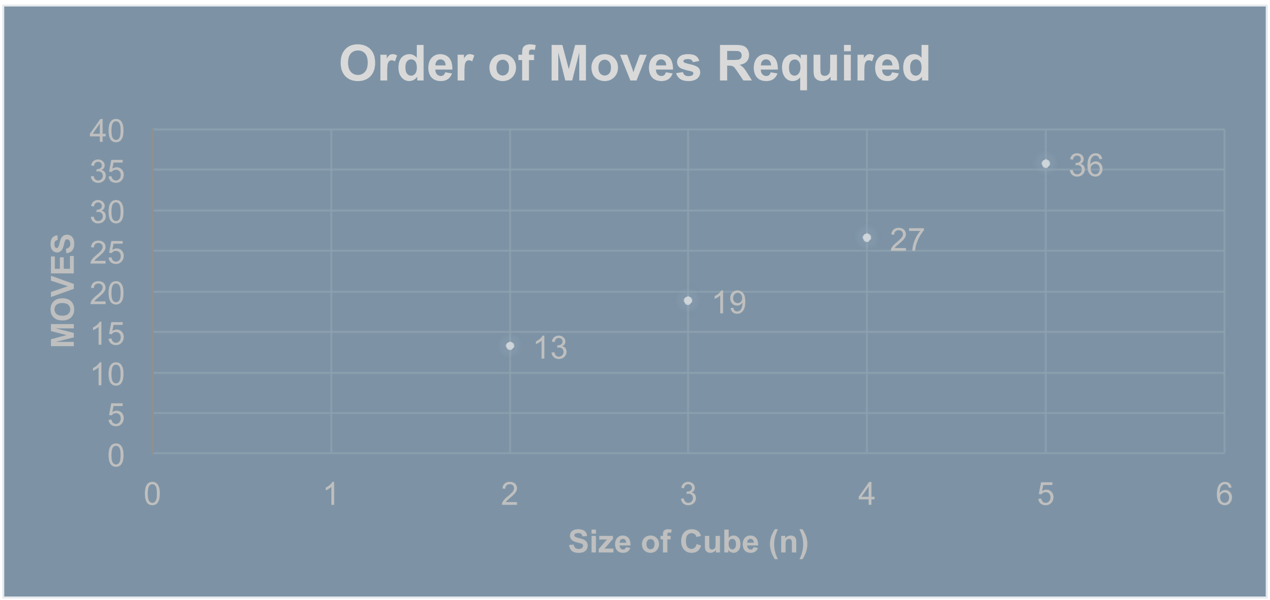
Many general solutions for the Rubik's Cube have been discovered independently. David Singmaster first published his solution in the book *Notes on Rubik's "Magic Cube"* in 1981.[30] This solution involves solving the Cube layer by layer, in which one layer (designated the top) is solved first, followed by the middle layer, and then the final and bottom layer. After sufficient practice, solving the Cube layer by layer can be done in under one minute.

Other general solutions include "corners first" methods or combinations of several other methods. In 1982, David Singmaster and Alexander Frey hypothesized that the number of moves needed to solve the Rubik's Cube, given an ideal algorithm, might be in "the low twenties".[34] In 2007, Daniel Kunkle and Gene Cooperman used computer search methods to demonstrate that any 3×3×3 Rubik's Cube configuration can be solved in 26 moves or fewer.[35][36][37]

In 2008, Tomas Rokicki lowered that number to 22 moves,[38][39][40] and in July 2010, a team of researchers including Rokicki, working with Google, proved the so-called "God's number" to be 20.[41][42] This is optimal, since there exist some starting positions which require at least 20 moves to solve. More generally, it has been shown that an $n \times n \times n$ Rubik's Cube can be solved optimally in $\Theta(n^2 / \log(n))$ moves.[43]

MORE MATH -- Moves to solve

- It has been shown that an *n* × *n* × *n* Rubik's Cube can be solved optimally in $\Theta(n^2 / \log(n))$ moves.



- Demaine, Erik D.; Demaine, Martin L.; Eisenstat, Sarah; Lubiw, Anna; Winslow, Andrew (2011). "Algorithms for Solving Rubik's Cubes". v arXiv:1106.5736 [cs.DS].

Some Women in STEM

My Favorites

SOPHIE GERMAIN

Mathematician

Specialty	**Physicist, philosopher**
Born	**Apr. 1, 1776 Rue Saint-Denis, Paris, France**
Died	**June 27, 1831 (at age 55) Paris, France**
Nationality	**French**

Sophie was an avid reader as her father had a large library and she even taught herself Greek and Latin. Upon reading Montuclas *The History of Mathematics*, she was so fascinated by the life and death of Greek mathematician Archimedes that, at the young age of 13, she decided to purs her studies in mathematics, despite being discouraged by her parents.

Fearful of the ridicule associated at that time with female scientists, yet resourceful and determined, Sophie used the male pseudonym Monsieur Le Blanc in order to have access to various lecture notes for academic courses held at the Ecole Polytechnique near Paris.

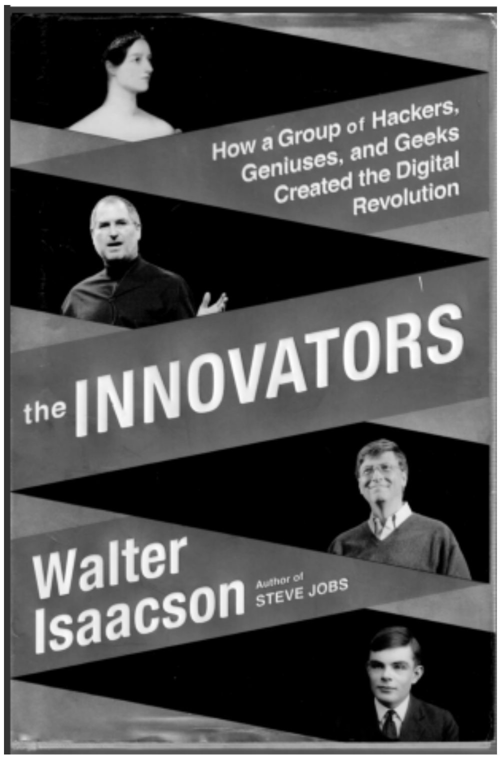
When she submitted her written observations, which was a requirement of t Polytechnique, to mathematician Lagrange, the faculty member was so impressed that he requested to meet the brilliant student who turned out to b a young girl, a fact which did not bother him at all.

In 1806, Napoleon's armies were marching into Prussia, and Germain bec concerned that Gauss might be in danger. She asked a friend who was a commander in the French artillery to find Gauss and ensure his safety. Her friend followed her request—but revealed her identity in the process.

Gauss initially responded with delight, writing to Germain: "The taste for the abstract sciences in general and, above all, for the mysteries of numbers, is very rare. But when a woman, because of her sex, our customs and prejudices, encounters infinitely more obstacles than men in familiarizing herself with their knotty problems, yet overcomes these fetters and penetrat that which is most hidden, she doubtless has the most noble courage, extraordinary talent, and superior genius."

ADA LOVELACE

First Computer Programmer



LADY LOVELACE'S OBJECTION

Ada Lovelace would have been pleased. To the extent that we are permitted to surmise the thoughts of someone who's been dead for more than 150 years, we can imagine her writing a proud letter boasting about her intuition that calculating devices would someday become general-purpose computers, beautiful machines that can not only manipulate numbers but make music and process words and "combine together general symbols in successions of unlimited variety."

Machines such as these emerged in the 1950s, and during the subsequent thirty years there were two historic innovations that caused them to revolutionize how we live: microchips allowed computers to become small enough to be personal appliances, and packet-switched networks allowed them to be connected as nodes on a web. This merger of the personal computer and the Internet allowed digital creativity, content sharing, community formation, and social networking to blossom on a mass scale. It made real what Ada called "poetical science," in which creativity and technology were the warp and woof, like a tapestry from Jacquard's loom.

Ada might also be justified in boasting that she was correct, at least thus far, in her more controversial contention: that no computer,

EDITH CLARKE

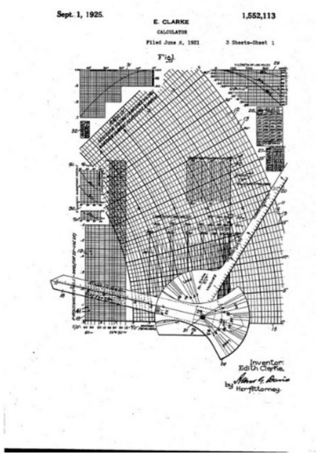
rn	February 10, 1883 Howard County, Maryland
ed	October 29, 1959 (aged 76)
esidence	Massachusetts, United States
tionality	American
elds	Electrical Engineering
stitutions	General Electric University of Texas at Austin
ma mater	Vassar College Massachusetts Institute of Technology
otable awards	National Inventors Hall of Fame

Girl Power: Barrier-Busting Electrical Engineer Joins Edison, Tesla in National Inventors Hall of Fame

http://www.gereports.com/post/110659530010/girl-power-barrier-busting-electrical-engineer

Edith Clarke lived in a pre-computer era when the few women with science education worked mostly as “human computers,” helping their male colleagues solve labor-intensive equations. But Clarke, who was the first woman to receive a degree in electrical engineering from the Massachusetts Institute of Technology (MIT), rebelled against that reality. “I had always wanted to be an engineer, but felt that women were not supposed to be doing things like studying engineering,” she later told *The Dallas Morning News*.

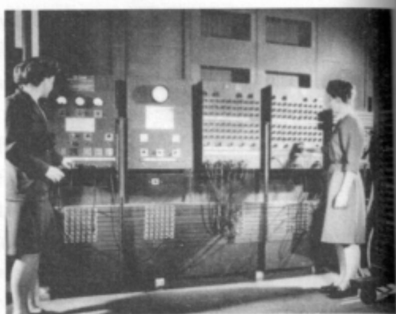
Last month, Clarke got the last of her many satisfactions. She was elected into the National Inventors Hall of Fame [NIHF], a rarefied group of some 500 engineers and scientists whose technological achievements have changed the U.S. and beyond. “In effect, she wrote what now would be called software for machines that set the stage for electronic digital computers,” says James E. Brittain in an early profile of Clarke, who alternated between roles at GE and in academia throughout her career.



Edith Clarke’s graphical calculator for solving power transmission problems. Image credit: NIHF

GRACE HOPPER AND THE "COMPUTERS"

ward Aiken and Grace Hopper (1906–92) with
art of Babbage's Difference Engine at Harvard
946.



Jean Jennings and Frances Bilas with ENIAC.

Jean Jennings (1924–2011) in 1945.

Betty Snyder (1917–2001) in 1944.

twelve-fold increase *after* adjusting for inflation.) She started out majoring in journalism, but she hated her advisor so switched to math, which she loved.

When she finished in January 1945, her calculus teacher showed her a flyer soliciting women mathematicians to work at the University of Pennsylvania, where women were working as "computers"—humans who performed routinized math tasks—mainly calculating artillery trajectory tables for the Army. As one of the ads put it:

> Wanted: Women With Degrees in Mathematics.... Women are being offered scientific and engineering jobs where formerly men were preferred. Now is the time to consider your job in science and engineering.... You will find that the slogan there as elsewhere is "WOMEN WANTED!"[23]

Jennings, who had never been out of Missouri, applied. When she received a telegram of acceptance, she boarded the midnight Wabash train heading east and arrived at Penn forty hours later. "Needless to say, they were shocked that I had gotten there so quickly," she recalled.[24]

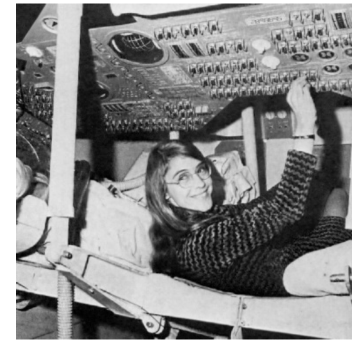
When Jennings showed up in March 1945, at age twenty, there were approximately seventy women at Penn working on desktop adding machines and scribbling numbers on huge sheets of paper. Con-

MARGARET HAMILTON

orn	1936 (age 78–79) Paoli, Indiana
lucation	University of Michigan Earlham College
ccupation	CEO of Hamilton Technologies, Inc. **Computer scientist**

Margaret Heafield Hamilton (born 1936)[1] is a computer scientist, systems engineer, and business owner.

She was Director of the Software Engineering Division of the MIT Instrumentation Laboratory, which developed on-board flight software for the Apollo space program.



Hamilton's team's work prevented an abort of the Apollo 11 moon landing.[3] In 1986, she became the founder and CEO of Hamilton Technologies, Inc. in Cambridge, Massachusetts. The company was developed around the Universal Systems Language based on her paradigm of Development Before the Fact (DBTF) for systems and software design

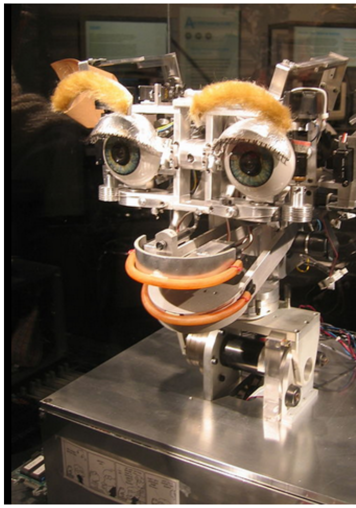
Hamilton has published over 130 papers, proceedings, and reports concerned with the 60 projects and six major programs in which she has been involved.

CYNTHIA BREAZEL

Breazeal in 2010
Computer Scientist
Robotics Expert

rn	November 15, 1967 (age 47) Albuquerque, New Mexico
tionality	USA

Cynthia Breazeal received her B.S. in Electrical and Computer Engineering from the University of California, Santa Barbara in 1989,[her S.M. in 1993 and her Sc.D. in 2000 in Electrical Engineering and Computer Science, both from MIT.

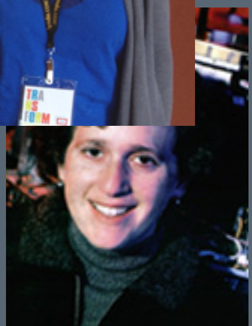


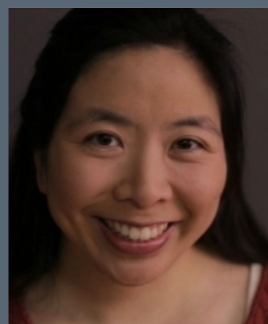
She developed the robot Kismet as a doctoral thesis looking into expressive social exchange between humans and humanoid robots. Kismet is internationally recognized, and is one of the best known robots developed to explore social and emotional aspects of human-robot interaction.

At the Media Lab, Breazeal continues to work on social interaction and socially situated learning between people and robots.

A. Goodman

domprasert





Astrophysics Researchers

Ambassadors for the
WorldWide Telescope

Alyssa A. Goodman is primarily interested in how the gas in galaxie constantly re-arranges itself over huge time spans to constantly forn new stars. She also has a long-standing interest in data *visualizatio* and in improving the use of *computers* in all aspects of scientific research. She teaches a course at Harvard called "The Art of Numbers."

She is working closely with colleagues at Microsoft Research, helpir to expand the use of the *WorldWide Telescope* program, in both research and in education. In 2009, Goodman founded the WorldWide Telescope Ambassadors Program which pairs PhD-level researchers with educators and outreach professionals to improve STEM teaching.

http://www.cfa.harvard.edu/~agoodman

Pat Udomprasert is the Director of the WWT Ambassador Program

http://wwtambassadors.org/people/pat-udomprasert

The WorldWide Telescope computer program (WWT) fro Microsoft Research is a stunningly beautiful and freely available tool offering immersive views of the sky and multimedia links to interactive descriptions and explanations of millions of celestial objects.

YOU?

NEW BEDFORD | 'THE MATHCATHALON'

The challenge: Making math fun

Kennedy Johnson, sixth-grader from Roosevelt, works Wednesday on solving Rubik's Cube puzzles. The MathCounts competition featured