Margaret Hamilton

“*One small step for man, one giant leap for mankind*”, the infamous words uttered by Neil Armstrong as Apollo 11 successfully completed the first lunar landing in history. The US had won the race to the moon, throwing Neil Armstrong and Buzz Aldrin into the limelight, but what about the brilliant minds working behind the scenes? If it were not for the intelligent software developed by Margaret Hamilton, a mathematics graduate and programmer at Massachusetts Institute of Technology, the Apollo 11 mission may not be remembered as the incredible success it was (McMillan, 2015). Hamilton worked tirelessly to differentiate this area of expertise from other typical practices of engineering, and is accredited with having coined the term “software engineering”. She later developed her own company, Hamilton Technologies Inc, to “accelerate the evolution of our technology” and make it more accessible to users (Hancock, 2014). Hamilton’s work was widely recognised by professionals in the field, but possibly the most prestigious award she received was the Presidential Medal of Freedom from Barack Obama in 2016, the highest civilian honour in the United States (BBC News, 2016). Hamilton was extremely influential to the development of software engineering as a profession, especially in the area of error handling and testing, and has led the way to software engineering as we know it.

# Apollo 11

Margaret Hamilton starter her career as a programmer for MIT in 1960, working to support her husband as he completed his studies at Harvard Law School (Stewart, 2017). Early in her career she was assigned responsibility to develop software to deal with an aborted mission- a trivial task that was given very little attention as her supervisors believed it was “never going to happen” (Brown, 2002). As time went on Hamilton had more people working for her in the systems area- focusing on operating systems, man machine interfaces and particularly error detection and recovery. At a conference for the “Apollo Guidance Computer History Project” in 2001, she recalled her curiosity and ambition to learn about “Auge Kugel”- a method of error detection that would later benefit her work in Apollo 11 (Brown, 2002).

Hamilton’s career really began to take flight thanks to the Apollo program that was launched by John F. Kennedy in 1961. Hamilton, alongside her colleagues at the MIT Instrumentation Lab, began writing code for the world’s first portable computer (McMillan, 2015). At the time software engineering was an unexplored area, Hamilton described the venture into systems programming as similar to entering the “Wild West”, proclaiming that “there was no course in it. They didn’t teach it” (Stewart, 2017). It is hard to believe that the original document outlining the engineering requirements of Apollo 11 didn’t even mention the word software! (McMillan, 2015).

The US became extremely dependant on Hamilton’s work, appointing her responsibility for the onboard flight software on the Apollo Computers (McMillan, 2015). During an Apollo 8 mission, Hamilton’s four-year-old daughter Laura began playing with the MIT command module simulator’s display and keyboard unit. Somehow. Laura launched a prelaunch program while the simulator was mid-flight, causing an error message to appear (McMillan, 2015). Hamilton requested permission to include more error detection and recovery in her software, but this request was denied by NASA who believed their astronauts were too intelligent to make mistakes. Hamilton compromised, and during Apollo 8- a mission run by Jim Lovell- they added a program note that read “do not select PO1 during flight” (Brown, 2002). Hamilton would later learn that the vigorous testing and error handling implemented in her code would be vital to the success of Apollo 11.

Hamilton poses with the Apollo guidance software she and her team developed at the MIT Instrumentation Laboratory. (Howell, 2016)

Just as the astronauts were about to land, the normal mission sequences were overridden with error- giving the astronauts a go/no go decision. The astronauts put their faith in the software, and proceeded with their mission becoming the first people to walk on the moon. Hamilton ensured a fault analysis was completed, which showed that an error had occurred in the hardware. This led to the CPU becoming overloaded with a queue of processes, but luckily Hamilton had prepared for such a situation (Howell, 2016).

The code that Hamilton and her team developed focused on asynchronous and priority scheduling software, meaning that computer performed tasks of the highest priority first, rather than the typical “first in first out” schedule. Standard and less necessary functions were put on hold until the priority tasks were completed (Kimball, 2016). As the 1201/1202 alarms sounded on Apollo 11, the computer was smart enough to recognize it was being asked to perform more tasks than it could handle. The alarms were a signal to the astronauts that the computer had recognized the error conditions, and the software was equipped with recovery programs that eliminated lower priority tasks and focused only on the necessary procedures for landing (Hancock, 2014). The intelligent software recognized the problem and intervened, safely landing Apollo 11 on the surface of the moon.

Rigorous testing and simulation fuelled Hamilton’s confidence in her software, even in this time of panic. Running tests on the ground demonstrated the relationship between software, hardware and the astronaut, and highlighted potential errors that could occur. Hamilton recognised it was critical to understand errors if she wanted to prevent them reoccurring in future missions. She realized that interface errors accounted for 73% of errors, and developed a theory called Higher Order Software, which contained six axioms that define software in such a way that these errors can be avoided. Alongside this, it was discovered that 44% of errors could be found using the “Auge Kugel” method, a method by which you analyse data as if you were the computer (Brown, 2002).

During Apollo Hamilton began working with Universal Systems Language, which she correlates to a root canal surgery. She focused on a preventative method of software engineering whereby errors are corrected at the start, rather than at the end (Rothman, 2015). This was revolutionary to the software engineering industry. The cost of testing code can be greatly reduced by detecting problems in advance, leading to smaller budgets for software engineering projects that are more likely to get approved. For this reason, Hamilton believes software reliability is the key to future exploration of the universe (Rothman, 2015). This concept of finding errors before the fact has been developed in our CS3012 module, as we hunt for possible errors before writing our code, and when writing our code, we provide against such errors.

# Hamilton Technologies

Hamilton founded her second company, Hamilton Technologies, in 1986 and is currently the CEO at 80 years of age. Through this her work has evolved to theories such as Development Before the Fact (DBTF), a software development methodology by which each system has defined properties that control its design and development. Through this system, emphasis is placed on defining things at the right time which prevents problems before they happen (Gee, 2016). DBTF acted as the foundations for Universal Systems Language, which is “a modelling language and formal method for the specification and design of software and other complex systems” (Gee, 2016).

# The Birth of Software Engineering

As the project unfolded it became evident that the US would depend on software to win their race against the Russians to the moon. Hamilton and her colleagues were not only programming the Apollo spacecraft, but were also formulating a $400 billion industry. This was the first computerized onboard navigation system that could be operated by humans, and it fed into the computerized navigation systems that are now on standard jetliners (McMillan, 2015).

Although software was fundamental to America’s victory in the race to the moon, in the early days of the Apollo project it was not taken as seriously as other aspects of the mission. In Hanock’s paper “Margaret Hamilton, the Engineer Who Took the Apollo to the Moon”, Hamilton recalls how co-workers “liked to kid me about my radical ideas” when she first introduced the concept of software as an engineering discipline, separate from hardware or other forms of engineering. Margaret Hamilton developed the building blocks for modern software engineering, and in fact coined the term “software engineering” (Rayl, 2008).

# Female Role Model

In a sector mainly dominated by males, Margaret Hamilton is an inspiration for women working in science and technology. At the time of Apollo 11, women working in branches such as computer science were normally regulated to lower positions (Hancock, 2014). However, Hamilton and her co-workers were extremely dedicated to the mission, and worked together to tackle problems. They were so intently focused on what they were trying to achieve that gender never came into the equation. The only element that differentiated one co-worker from another was their area of specialization (Gee, 2016). This is encouraging to women who wish to pursue a career in STEM subjects, as it shows her dedication to her work and technical capability outweighed her gender.

# Achievements

Hamilton’s work has not gone unnoticed, having received the highest civilian award in the United States, the Medal of Freedom, from President Barack Obama in 2016. Obama commended her for developing software that “echoes in countless technologies today”, and accredited the success of Apollo 11 to Mrs Hamilton, saying "Our astronauts didn't have much time, but thankfully they had Margaret Hamilton” (BBC News, 2016). In 2003, Hamilton was presented the NASA Exception Space Act Award for her contributions in science and technology, and received a cheque for $37,200, the largest sum received by an individual in NASA’s history. During this presentation Hamilton’s concepts of asynchronous software, priority scheduling and rigorous testing but to name a few were highlighted as the foundation for ultra-reliable software design (Gee, 2016).

Hamilton’s accomplishments are copious, and her ground-breaking work as one of the first pioneer software engineers can be seen in many current practices of software engineering. Without her planning and strive for perfection, the Apollo 11 mission may never have been a success. An imagine of Hamilton alongside the code for Apollo 11 which she had written by hand landed her in the social media spotlight, as many were utterly astounded by the work she had done. Hamilton’s triumph remains a beacon of hope for men and women alike, and we can confirm that Armstrong’s “one small step for man”, would never have been possible was it not for Hamilton’s small tweak to her coding.

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