Margaret Hamilton

"A mathematician and computer scientist who started her own software company, Hamilton contributed to concepts of asynchronous software, priority scheduling and priority displays, and human-in-the-loop decision capability, which set the foundation for modern, ultra-reliable software design and engineering."
-Quote from Presidential Medal of Freedom recipients 2016 (whitehouse.gov, 2016).

Margaret Hamilton is renowned for her work on NASA's Apollo missions, coining the term "Software Engineer" as well as starting up two companies with the interest of progressing the ideas of "development before the fact" programming methods, a technique for combatting the time and energy spent resolving coding errors. She helped set the standards for the way programming is done today at a time when software engineering was recognised by few as an engineering discipline at all.

Born on August 17th, 1936 in Paoli, Indiana in the USA, Margaret Hamilton studied mathematics at the University of Michigan, graduating with a B.A. from Earlham College in 1958 (Wayne and Bailey, 2011). After spending a year teaching high school maths and French and marrying James Cox Hamilton, Hamilton developed weather prediction software for professor Edward N. Lorenz on the Librascope LGP-30 and PDP-1 computers (Computerhistory.org, 2017). At this time, since dedicated software development courses did not exist, Hamilton had to learn to build software on her own "with Lorenz's guidance" (Creighton, 2016).

Hamilton further increased her understanding of software development when she worked on the Semi-Automatic Ground Environment (SAGE) project for the MIT Lincoln Laboratory from 1961 to 1963 (Computerhistory.org, 2018). The SAGE was the first US air defence system built in response to the discovery that the Soviet Union had developed nuclear weaponry as well as the means to use them on the US (Ll.mit.edu, n.d.). Hamilton wrote software on the first AN/FSQ-7 the XD-1 which was used to detect foreign aircrafts (Creighton, 2016). While working on this project, Hamilton simultaneously wrote software for satellite tracking at the Air Force Cambridge Research Laboratory (Wayne and Bailey, 2011). It was here that Hamilton began to develop an interest in software reliability which would be a key focus throughout her career (Computerhistory.org, 2018). Hamilton stated "When the computer crashed during the execution of your program, there was no hiding. Lights would be flashing, bells would be ringing and everyone, the developers and computer operators, would come running to find out whose program was doing something bad to the system." (Creighton, 2016).

At this point, Hamilton returned to MIT, joining the Charles Stark Draper Laboratories, who at the time were designing the onboard computers and guidance systems for the Apollo missions (The Charles Stark Draper Laboratory, Inc., 1976). This was one of the first times software would be entrusted with such "mission critical, real time tasks" (WIRED, 2014) Hamilton became assistant director of software engineering (Wayne and Bailey, 2011) and lead the team that were responsible for writing and testing the code for these systems (The

Charles Stark Draper Laboratory, Inc., 1976). The testing for this code needed to be meticulous, with Hamilton saying later "There was no second chance. We all knew that" (Rayl, 2008). Her team had to anticipate all possible eventualities and ensure the computers were prepared for them (Wayne and Bailey, 2011) and Hamilton established rigorous requirements for the engineering process and debugging for each subsystem and component to meet these demands. The work that Hamilton did here became the groundwork for her Universal Systems Language and Development Before the Fact (DBTF) formal systems theory, both of which became the focus of her work after NASA (Rayl, 2008). Nowadays, all software systems demand this level of testing, and the work Hamilton and the rest of her team did pioneered these methodologies.

The onboard computers needed to be able to take inputs from Mission Control, the various on-board applications such as the radar and the astronauts piloting the craft, so a key component of the computer's operations was to establish what order these jobs would need to be done in (Wayne and Bailey, 2011). To respond to this, Hamilton built the Priority Displays error detection and recovery programs. This program allowed the software to interrupt what the astronauts were doing replacing their displays with priority displays to warn them in case of an emergency (Computerhistory.org, 2018). It also created a new "man in the loop" concept whereby the astronauts could be involved in the decisions being made by the computer.

This became an integral part of the Apollo 11 moon landing, and Hamilton stated that without it "I doubt if Apollo 11 would have been the successful moon landing it was." (Hamilton, 2014). Due to a misplaced radar switch, the computer was receiving additional data while attempting to land. The software recognised that it was being asked to complete more tasks than it should and was able to use the priority display to inform the astronauts that it was going to prioritise the landing functions, "eliminating lower priority tasks and re-establishing higher priority ones" (Hamilton, 2014). By using the priority display, Dan Lickly, director of mission program development at the MIT Instrumentation Lab at the time recalls, the team could quickly identify the problem and give the astronauts the green light to continue with the landing (MIT News, 2009). Without this program, it is possible that the moon landing would not have occurred (Rayl, 2008). The success of this piece of software at such a pivotal moment in the mission is largely seen as one of Hamilton's key contributions to software engineering (whitehouse.gov, 2016).

Around this time Hamilton had her first and only child, Lauren Hamilton. To maintain her work-life balance, Margaret Hamilton spent "as much time as possible with my daughter by taking her to work with me during nights and weekends." (Creighton, 2016) For Hamilton to do this showed her dedication to the work she was doing while also valuing the relationship she was nurturing with her child.

At the time Hamilton was working on the Apollo missions, software development was not as respected as other branches of engineering. Hamilton, to give software development "its due respect" coined the term "Software Engineering". At the time of the Apollo missions, software development was poorly understood. While at first this name was taken as a joke, (Hamilton, 2014), software engineering eventually established itself as a unique and relevant engineering discipline "Software, a concept barely understood at the start of Apollo, became critical during its development" (Mindell, 2011). As Mindell discusses, the Apollo missions had a profound and lasting effect on the world's view of software development, and engineers like Margaret Hamilton were at the forefront of this change.

After NASA fully took over the Apollo project from MIT, Hamilton consulted on preliminary software system requirements for the NASA's Space Shuttle and Skylab's on-board flight software programs (Hamilton, 2014) as well as several projects at MIT such as overseeing a biomedical bedside computer, control systems for aircrafts and air traffic control instrumentation (Wayne and Bailey, 2011). She also led her team to perform empirical analysis based on what they had learned from working on the Apollo missions. This became the bases for Hamilton's Universal Systems Language (USL), a "preventive, development before the fact philosophy that does not allow errors in the first place" (H. Hamilton and R. Hackler, 2008). Wishing to further her career in error development, Hamilton co-founded Higher Order Software Inc. (HOS), a company for developing software to identify mistakes in code before they occurred also called Development Before the Fact (DBTF) (Wayne and Bailey, 2011).

Higher Order Software proposed the implementation of their "USEIT" tool which could generate code in various languages. This method was noted to have received "very little response" and one from the US Navy stated that "no formalism has been developed that is uniformly adequate for all phases of system development. AXES and the HOS methodology are no exception." (G. M. Huber, 1987). HOS was ultimately unsuccessful.

Despite this, Hamilton wished to publicise what she and her team had learned from the Apollo missions, and Hamilton left HOS to found Hamilton Technologies Inc. in 1986 to develop Universal Systems Language (USL), another Development Before the Fact methodology. The objective of USL among other things is to reduce problem complexity, ensure correctness by built in language properties and eliminate the large amount of testing without sacrificing any reliability (H. Hamilton and R. Hackler, 2008). Instead of looking for ways to test for errors throughout the software development cycle, USL is designed so that most errors do not make it into the system in the first place (Computerhistory.org, 2017). USL is designed to be used along with the 001 Tool Suite throughout the software development process to ensure these objectives. (htius, n.d.) As of 2014, despite being 78 years old at the time of this interview, Hamilton continues to work on the improvement of USL and the 001 Tool Suite in the hopes of "accelerate the evolution of our technology and to introduce it to more users." (Hamilton, 2014).

In recent years, Hamilton has received several awards for her contribution to the success of the Apollo missions and reliable software design. She was awarded the Ada Lovelace award, an award given to "individuals who have excelled in either (or both) of two areas: Outstanding scientific and technical achievement, and extraordinary service to the computing community through their accomplishments and contributions on behalf of women in computing (Association for Women in Computing, n.d.). In 2003 she received the

NASA's Space Act Award for “scientific and technical contributions” to the Apollo missions (Braukus, 2003). On top of this, in 2016 she received a Presidential Medal of Freedom from former president Barack Obama (whitehouse.gov, 2016) and in 2017 LEGO released a “Women of NASA” set featuring a figure of Hamilton along with Nancy Grace Roman, Sally Ride and Mae Jemison (Shop.lego.com, 2017).

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