Progress Report
Team 2: ULTRARAM

CERN IdeaSquare Summer School 2023

Executed and written by:

Jakub Barciński
Krijn Dignum
Javier Páez Franco
Miłosz Pluciński

Starting date: May 24th 2023 *Completion date: September 1st 2023*

Table of Contents

PART 1

Introduction

The CERN IdeaSquare Summer School is an esteemed program that brings together a diverse group of undergraduate and postgraduate students from various scientific and technical disciplines. This annual event, organized by the European Organization for Nuclear Research (CERN), in collaboration with Dutch universities: Delft University of Technology, Erasmus University Rotterdam, and the University of Amsterdam, serves as a catalyst for innovation and creative thinking at the forefront of technology, particle physics, and engineering. Throughout this immersive experience, participants engage in hands-on projects, collaborate with leading researchers, and gain access to state-of-the-art facilities. The summer school not only fosters a stimulating environment for learning but also encourages interdisciplinary collaboration, critical thinking, and the exploration of groundbreaking ideas.

This report was written by **Team 2** (team name: ***La Familia***) of the 2023 Summer School. The team consisted of four members: Jakub Barciński (Delft University of Technology, Aerospace Engineering), Krijn Dignum (University of Amsterdam, Artificial Intelligence), Javier Páez Franco (Delft University of Technology, Computer Science), and Miłosz Pluciński (Delft University of Technology, Aerospace Engineering).

The 2023 edition of the summer school kicked off on 24 May 2023, starting with a series of 5 weekly introductory lectures. Then, between 10 and 12 July 2023, a three-day design sprint took place in Delft and Amsterdam. Finally, the main part of Summer School was held in Geneva from July 21 to July 29, 2023.

In this Progress Report, we aim to document our journey, accomplishments, and discoveries during the summer school, highlighting the valuable insights gained, and the contributions made to the scientific community as well as our own personal development.

The structure of this report is as follows. First, the team is introduced, together with the background of every member and results of team building exercises. The next chapter describes the innovation process throughout the whole course, and is followed by the detailed description of the final concept. Finally, the report is summed up by an individual reflection abut the course of every team member.

PART 2

Team

2.1 Team background

Team 2 *La Familia* was made up of four members: Jakub Barciński, Krijn Dignum, Javier Páez Franco, and Miłosz Pluciński. For many of the team members, this was the first chance for not only inter-faculty collaboration, but also for working with students from other university. This section presents a brief background for every team member.

Jakub Barciński:

Jakub Barciński is a bachelor student at the Faculty of Aerospace Engineering at Delft University of Technology in the Netherlands. His choice of study was driven by his passion for futuristic technologies, and a fascination about all the technical aspects behind motorsport vehicles. For his Honours programme research project, he is investigating the use of helium-filled soap bubbles generated by an ergonomic portable device as a form of flow visualization in aerodynamic applications.

Jakub applied for the Summer School as he was eager to get the opportunity to approach a task from a totally different perspective than he is taught on his bachelor study. Moreover, with Jakub being an outgoing person, he was excited about the prospect of working on an interdisciplinary project with peers from different Faculties and Universities at the well-renowned and history-rich CERN Institute.

Krijn Dignum:

Krijn has a keen eye for design, taking pleasure in well-crafted products, whether it's a website or a piece of furniture. He firmly believes in the necessity for humans to align more closely with nature and to care more deeply for the earth. As a student of Artificial Intelligence, Krijn holds the conviction that technology can offer solutions to many of humanity's pressing challenges. He sees the potential for AI to help steer humanity in the right direction and even ”save humans from themselves.” By engaging in various projects, Krijn seeks to expand their knowledge on new technologies that will shape our future.

Javier Páez Franco:

Javier Páez Franco is a passionate Computer Science and Engineering student enrolled at Delft University of Technology in the Netherlands. He is currently part of the Honours programme, and his focus lies in the exciting realm of Robotics through the esteemed Next Generation Robotics (NGR) programme. His love for both technology positions him as a great help for evaluating the technological feasibility of ideas, while his willingness to experiment and iterate infuses the prototyping process with enthusiasm.

The dream of visiting CERN, one of the biggest research institutes and where the web was born, and Javier's interest in entrepreneurship and business further compelled him to seek out this opportunity.

With a strong desire to gain valuable experience working in a multidisciplinary team, he eagerly looks forward to embracing this transformative course. He is excited to embrace this transformative experience, eager to learn, collaborate, and contribute to its success.

Miłosz Pluciński:

Miłosz Pluciński is a curious Aerospace Engineering student at Delft University of Technology in the Netherlands. He is pursuing the Honours Program Delft and is diligently researching in the field of computer vision. On the side, he combines his love for football with machine learning insights, exploring the applications of data science in sports. His curiosity and drive to always find a solution led him to participate in the CERN IdeaSquare Summer School.

His original interest was in physics, which was his passion in high school and fueled his interest in the work done at CERN in Geneva. Even though the Summer School was not directly tied to particle physics research there, having the opportunity to work and rest in this environment made him even more eager to take on this challenge.

2.2 Team rules, Superpowers and Dragons

As soon as the team was formed, a set of team rules was discussed between the team members. The established guidelines were:

1. Everyone has a vote (democracy).
2. No fillers/unnecessary discussions.
3. Keep track of the amount of work left.
4. Equal distribution of work.
5. Always be honest.
6. Respect each other.
7. Have fun!

Furthermore, in order to find out the team's strengths and weaknesses, every team member shared their *superpower* (strength) and a *dragon* (weakness). These are shown on Figure 1. Fortunately, one team member's superpower accounted for another member's dragon, for example good time management could help with being unorganized and procrastination.

(a) Superpowers *(b) Dragons*

Figure 1: Team superpowers and dragons

PART 3

Innovation and ideation process

In this chapter, every step of our journey through the whole innovation process is outlined. We stared the process with familiarization with the technology. Once we felt confident, we started brainstorming potential applications. After arriving at 100 possible domains, we kept narrowing the amount of ideas down and digging deeper into each concept, until we arrived at the final three concepts that we liked the most.

3.1 UltraRAM Technology

UltraRAM is a memory technology that combines the best aspects of RAM, its fast speed and low energy consumption, and flash memory, its non-volatility and non-destructive read, with none of their disadvantages. It outperforms SSDs by up to 50 times in non-volatile storage time (1000 years) and consumes 100 times less energy than RAM and 1000 times less than flash. This groundbreaking technology opens a world of possibilities across industries, bringing us closer to a future where data storage is faster, more efficient, and built to stand the test of time.

An important step in unbundling the technology was the conversation with UltraRAM inventor Manus Hayne of Lancaster University, which took place on 29th July 2023. We found out that while the Lancaster team performed some basic experiments to demonstrate the principles in action, UltraRAM remains mostly theoretical at the moment. Some kind of Achilles heel might make it much more difficult to manufacture or apply on a mass scale. It is impossible to predict when or if something like this universal memory and storage solution could be brought to consumer devices, but it sure is an intriguing concept. UltraRAM pricing might be another thorny issue. If it is not price-competitive, its potential adoption rate, and transformative power, will be hindered. This economic factor remains to be seen, but the researchers were happy with the headlining silicon mass-production breakthrough of UltraRAM to make it accessible. The Lancaster University researchers say that further work is ongoing to improve quality, fine-tune the fabrication process, and implement and scale UltraRAM devices.

To make the principles behind the technology more understandable for every team member, but also for future conversations with other course participants or industry experts, we performed an exercise called ”We know how to...”, the goal of which is to explain what the technology can do with simple and clear terms. We managed to form three statements:

1. We know how to combine the speed and affordability of computer memory (RAM) with the ability to store data even when power is turned off, just like a hard drive (SSD), while using 100 times less energy than current RAM technology.
2. We know how to read and write operations without degrading.

3. We know how to use the memory to serve both as fast computer memory and long-term storage for files.

All of the above statements and remarks were summed up on a single canvas, as shown on Figure 2.

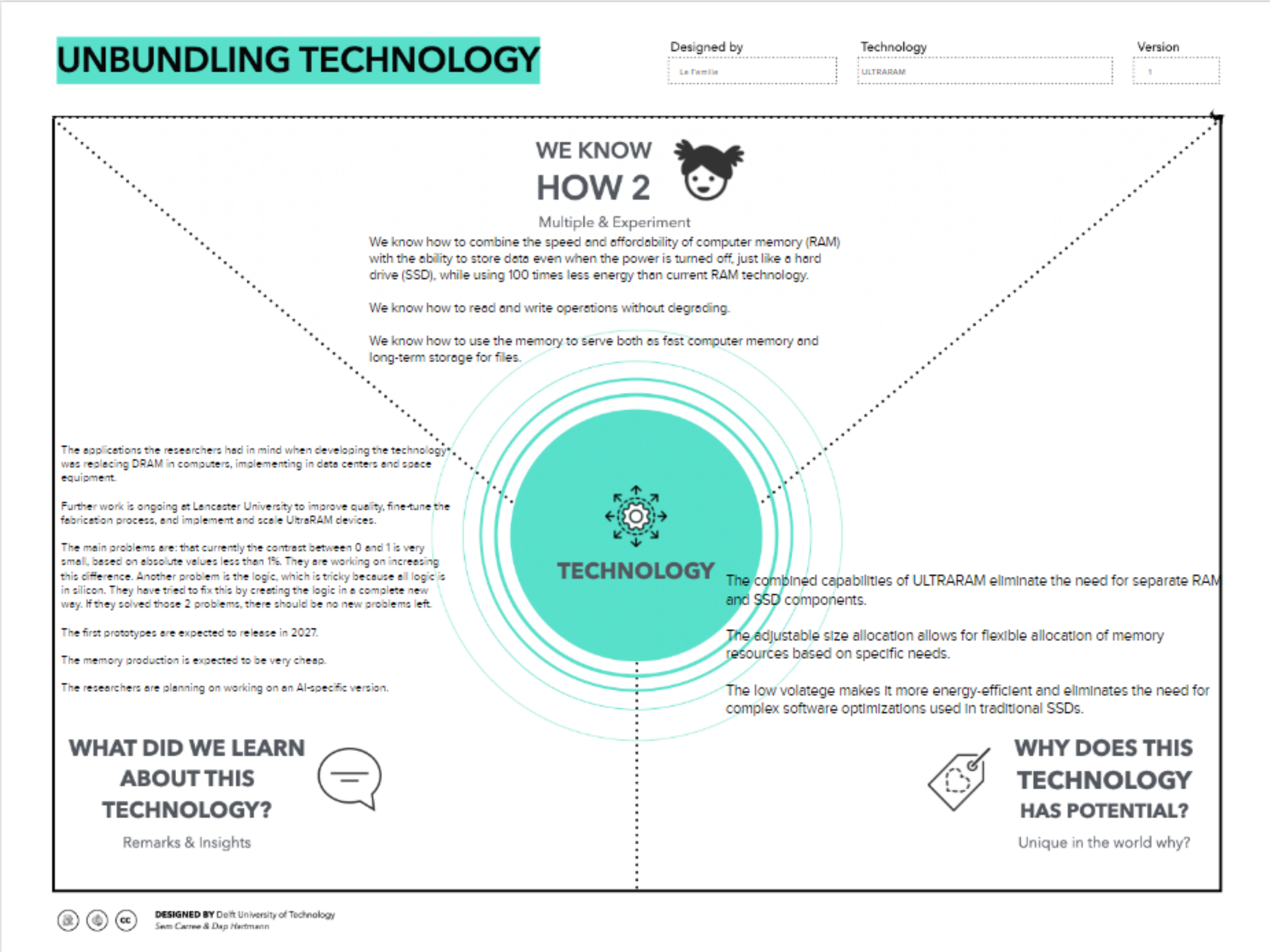


Figure 2: Technology unbundling

Moreover, Figure 3 shows very clearly the main capabilities of the UltraRAM technology, its strengths in comparison to conventional RAM and SSD memories, and some potential applications.

3.2 Domain exploration

Once we familiarized ourselves with the technology, we started brainstorming possible applications for UltraRAM. The goal of this brainstorming session was to arrive at a hundred different ideas, without any research into aspects like market, feasibility, etc. Then, the ideas were grouped into categories, which were: Biotechnology, Computer science & electronics, energy, business & finance, aerospace, media production, education, fashion & arts and other. While it is pointless to report all 100 ideas, Figure 4 shows two categories with the most entries: Computer science & electronics and business & finance.

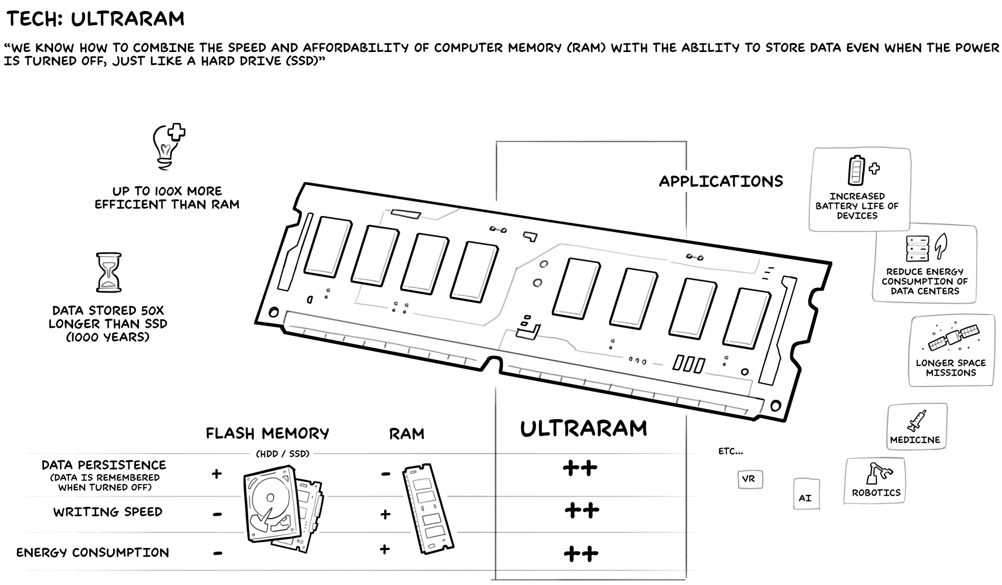


Figure 3: Visualisation of UltraRAM's capabilities

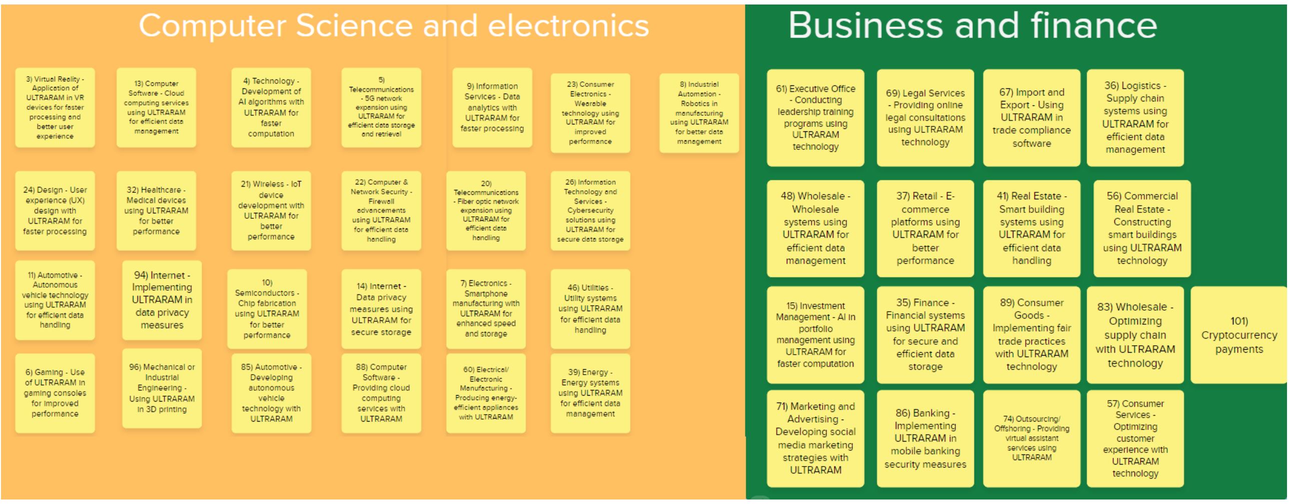


Figure 4: Two largest application domains

3.3 Narrowing it down - Tech-Applications fit

After brainstorming the possible applications domains, we selected 11 of them that we thought to be promising and have potential, and investigated them in more detail in an exercise called *Tech-Applications fit*. The goal of this task was to identify the key players and users in the domain, and think of all the opportunities, pains and potential applications inside the domain. The result of the exercise is shown on Figure 5.

In between the exercises we had a chance to create low-fidelity prototypes for the ideas we came up with. Each group member built their own prototype, and they illustrated the following applications: UltraRAM in car's onboard computer and sensors, UltraRAM in an USB drive, UltraRAM as a satellite memory, and UltraRAM used in VR device. Figure 6 show the pictures of automotive and satellite application prototype. These prototypes helped us visualize our ideas, as well as proved to be a useful

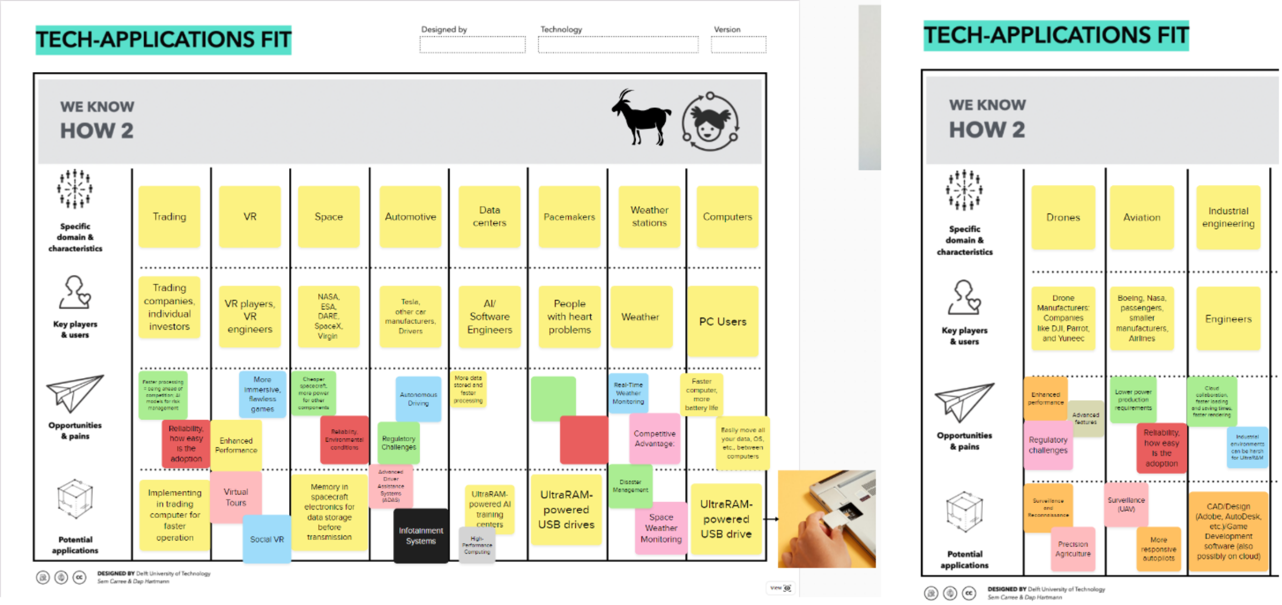
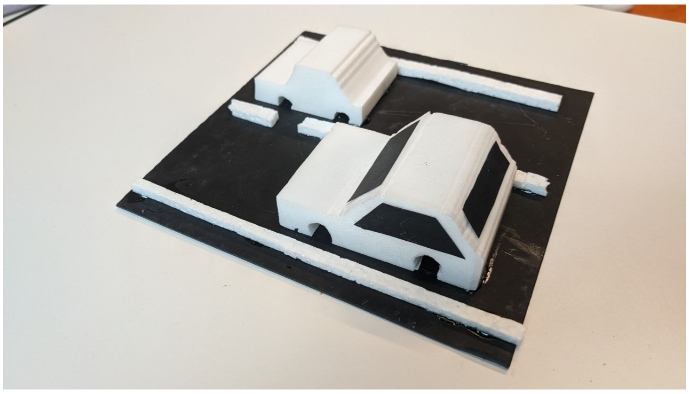
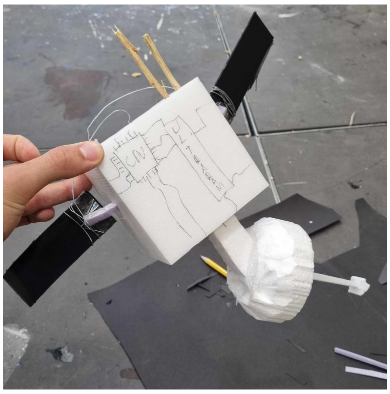


Figure 5: Tech-applications fit

tool to help explain the concept during dicussions with our peers.



(a) Car prototype



(b) Satellite prototype

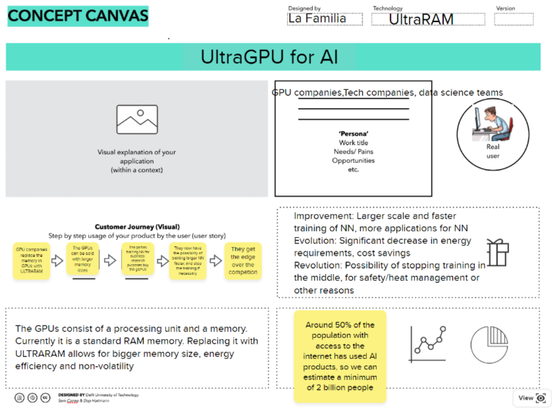
Figure 6: Early prototype

3.4 Final concepts

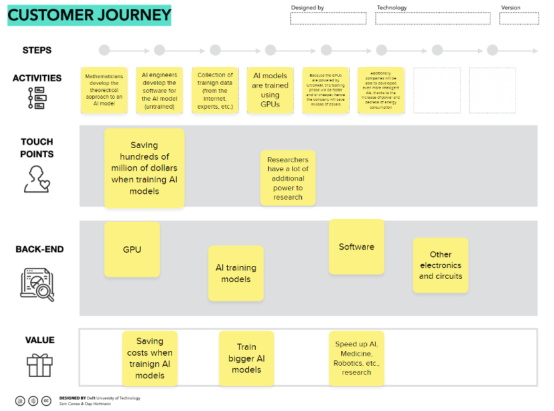
Having looked into several concepts as shown in the previous exercises, we spoke with several experts and scientists either present at CERN or online, in order to analyze their feasibility, impact and market potential. That led us to choosing three final concepts, with the goal to explore them even more thoroughly, and later ultimately choose one.

The following three concepts were developed:

- UltraGPU for AI - implementing UltraRAM in graphical processing units to enhance neural networks training and AI operations (Figure 7).
- UltraDrones - UltraRAM used as a memory in drones for onboard computer and storage (Figure 8).

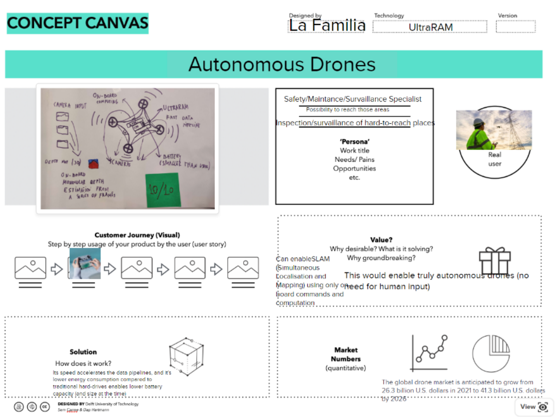


(a) Concept Canvas

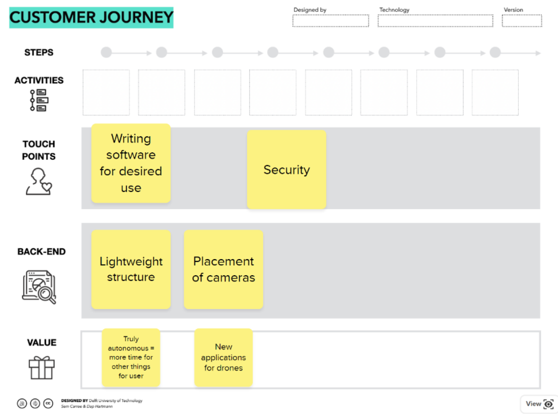


(b) Customer Journey

Figure 7: UltraGPU



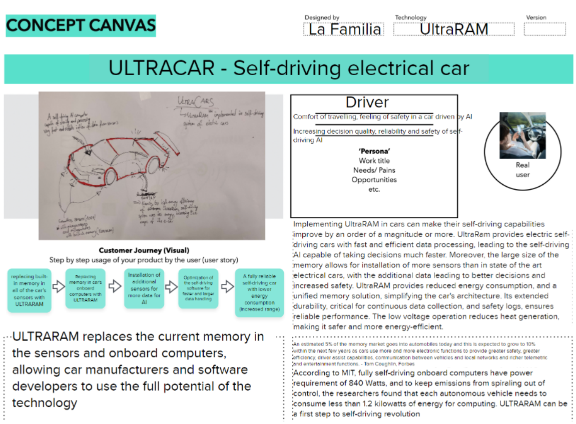
(a) Concept Canvas



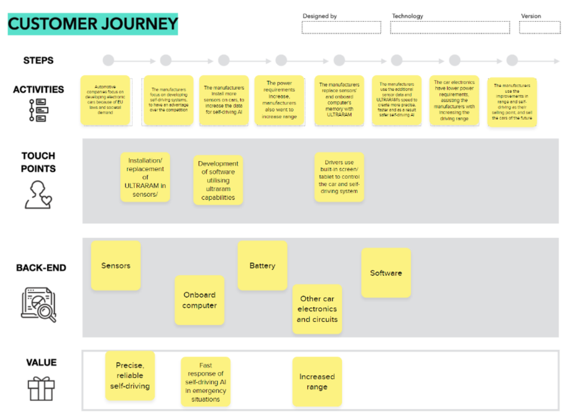
(b) Customer Journey

Figure 8: UltraDrone

- UltraCar - UltraRAM used in sensors and onboard computers of electric vehicles (Figure 9).



(a) Concept Canvas



(b) Customer Journey

Figure 9: UltraCar

Now, the final concept could be selected.

PART 4

Final concept

This chapter presents the result of our work - the final concept. Every key aspect is presented: First, a problem is defined, to which a solution and its value are thoroughly described. It is followed by some figures, showing the impact of our solution, and lastly, the accompanying prototype is presented.

4.1 Problem definition

In the last few years, the scale and demand for neural networks (NN) has been growing rapidly. Artificial neural networks have become a crucial tool not only for giant corporations, such as Google and Microsoft, for generating massive profits, but also for an average person, for instance, chatbots like ChatGPT. It seems that we are only at the beginning of an AI revolution, and different stakeholders involved in the AI industry are looking for solutions to problems associated with training larger and more complex artificial neural networks. These problems are:

- Massive energy consumption for NN training and associated environmental impact.
- Lengthy training times, limiting the iteration possibilities and NN sizes and complexity.
- Scaling challenges, limited by exponentially increasing energy consumption and operational costs.
- Thermal management as a consequence of high-energy requirements.

4.2 Description of solution

The main hardware component used for the training of modern neural networks is a graphical processing unit (GPU). Our application implements UltraRAM into the GPU memory as a replacement for the current memory technologies present in conventional components. By leveraging UltraRAM's fast access times and non-volatility, we can significantly accelerate NN training processes. This acceleration, coupled with the increased memory size compared to current RAM, enables researchers to train larger and more complex NN models, leading to improved accuracy and performance in various current applications and potentially unlocking new ones.

Furthermore, UltraRAM's low energy consumption and reduced heat generation translate to cost savings and improved thermal management, contributing to more energy-efficient and sustainable AI systems. Finally, the non-volatile nature of the memory allows for the training to be paused without losing progress, which may be convenient when dealing with large and complex data.

An example customer journey is as follows:

1. Discovery and Interest: Customers learn about the revolutionary application of UltraRAM for NN training and become intrigued by its potential benefits.
2. Product Research and Evaluation: Customers thoroughly research UltraRAM, exploring the case studies and testimonials to understand its impact on NN training.
3. Pilots and Proof of Concept: Some customers conduct pilot projects to test UltraRAM's performance and suitability for their NN training needs.
4. Validation and Adoption: Successful pilot projects convince more customers to adopt UltraRAM for faster training and increased energy efficiency.
5. Full Implementation and Integration: Customers fully integrate UltraRAM into their NN training pipelines for maximum benefits.
6. Scaling and Optimization: As UltraRAM becomes a core component, customers optimize and expand its usage for larger NN models and broader applications, utilizing the cost savings due to energy reduction for an increase in computational power.

The problem, solution and its value along with other factors are clearly summed up on a business canvas, which was one of the final steps in developing the concept, presented on Figure 10.

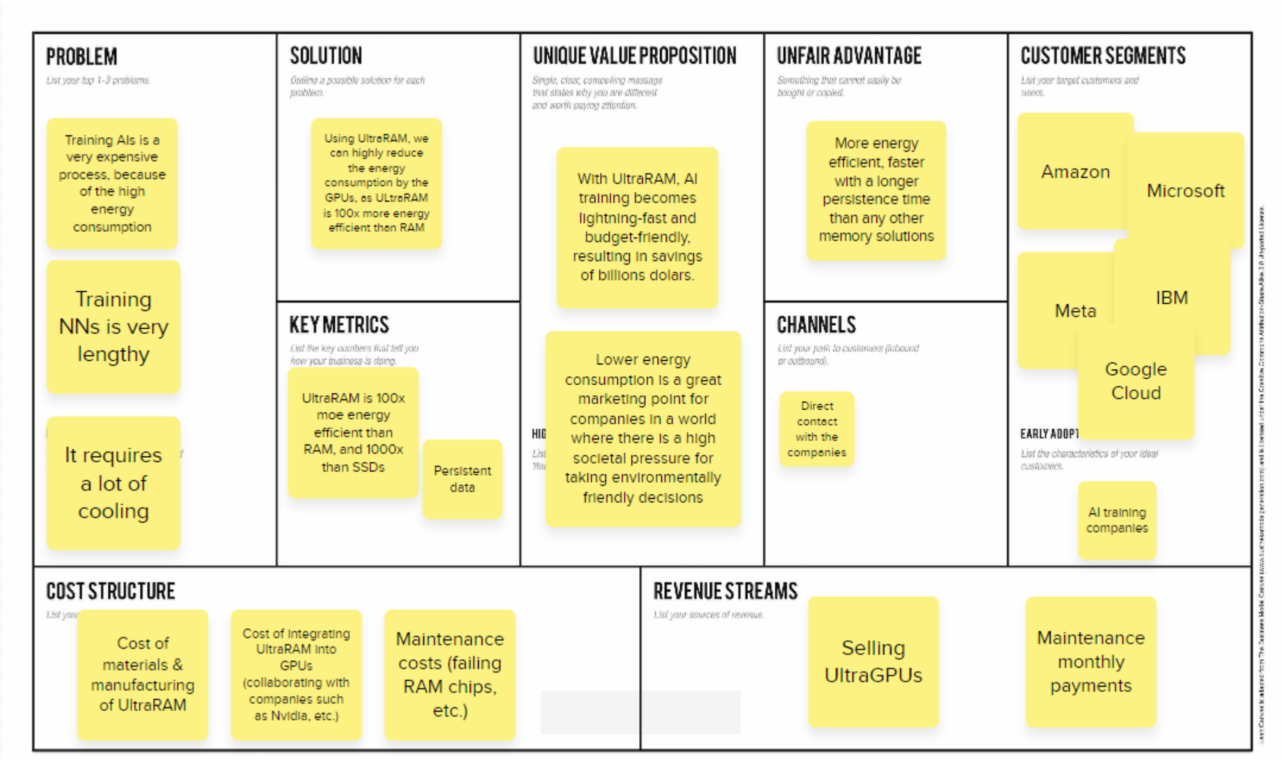


Figure 10: UltraGPU Business Canvas

4.3 Impact

It is hard to estimate exact numbers, such as megawatt hours of electricity or tonnes of CO_2 saved, due to the dynamic nature and the rapid growth of the AI industry. However, to highlight the enormous scale of the neural networks market and how impactful even 1% energy reduction is, one can cite the following facts:

1. Creating GPT-3 alone consumed 1,287 megawatt hours of electricity and generated 552 tons of carbon dioxide – (the equivalent of 123 gasoline-powered passenger vehicles driven for one year[1]) and 700,000 litres of water for cooling.
2. In 2021, Google's AI used around 2.3 terawatt hours of energy yearly, which is comparable to the electricity used by all residences in an Atlanta-sized metropolis[1].
3. The AI market value of nearly 100 billion U.S. dollars (2021) is expected to grow 20 times by 2030[2].

With UltraGPU, we are estimating a 99% energy consumption reduction of memory and a significant reduction in the consumption of a cooling system, such as fan or liquid cooling. In total, this should allow for up to 50% reduction of energy consumption in a whole GPU. Analysing the above numbers, it can be deduced that implementing this would be notably impactful for both the economy and the environment.

4.4 Prototype

The prototype of UltraGPU is presented in Figure 11. The main goal of our prototype is to compare a standard GPU with UltraGPU. To achieve that, a glass box was assembled and divided into two equal parts, each half representing the capabilities of each GPU technology. Both sides contain a 3D-printed model of a GPU, with UltraGPU given a more futuristic look to represent it being a technology of the future.

To highlight the reduction in energy consumption, there are 10 batteries "powering" a conventional GPU, while UltraGPU requires only one battery. This benefit is also shown on a small LCD screen, where arbitrary power consumption is presented, with UltraGPU consuming much less energy. Additionally, the screen shows a simulation of passing years, with conventional GPU dying after 10 years, whereas UltraGPU remains unharmed thanks to the durability of UltraRAM. To support that visually, next to the screen there are two sets of diodes where the flashing lights indicate that the GPU is running.

[1]www.euronews.com/next/2023/05/24/chatgpt-what-is-the-carbon-footprint-of-generative-ai-models
[1]www.tradealgo.com/news/the-carbon-footprint-of-artificial-intelligence-is-on-the-rise
[2]www.statista.com/statistics/1365145/artificial-intelligence-market-size/

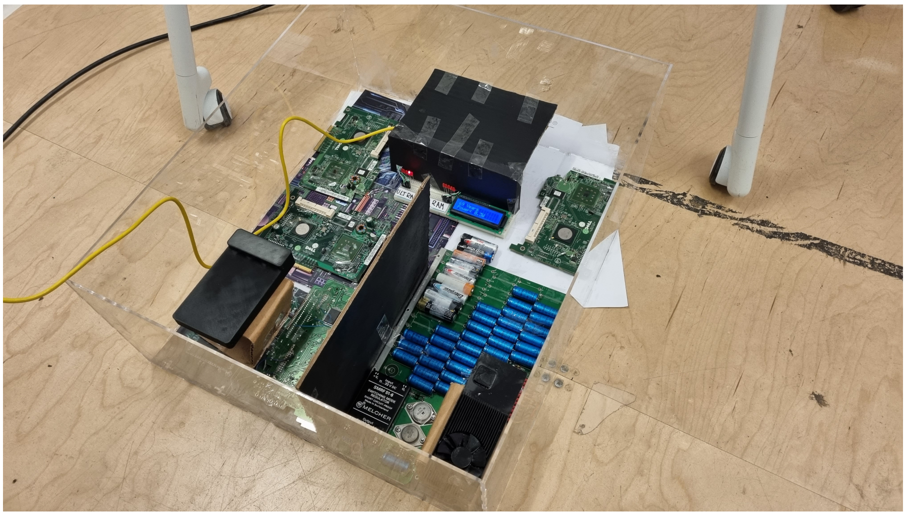


Figure 11: Prototype of UltraGPU

PART 5

Individual Reflection

This part of the report contains the individual reflection about the whole journey during the 2023 edition of CERN HPD Summer School of every team member:

Jakub Barciński:

The insight I learned during the Summer School that made the biggest impression on me is how important it is when developing a concept of a product, to constantly get in touch with potential customers and experts of the industry, gather their feedback and repeatedly analyse their needs.

Moreover, during the course I realised how difficult it is to think outside the box and come up with innovative ideas, all while not drifting away too much from the realms of feasibility and having a market for them. Contrary to strict engineering sciences that I am the most familiar with, there are no written down formulas that are guaranteed to give the desired result, but rather there is a variety of different tools that one can use to inspire and enhance creativity.

Overall, I am very satisfied that I participated in the CERN HPD Summer School. Not only did I learn valuable insights and broaden my perspective, but I also received the precious opportunity to engage with a multitude of people from different backgrounds.

Krijn Dignum:

Participating in the CERN HPD summer school was a transformative experience that reshaped my perspective on innovation and development. One of the standout realizations for me was the profound interplay between technological advancement and its environmental implications. As we delved deep into the intricacies of AI and its energy consumption, it became evident that pure innovation wasn't enough; sustainability had to be at the core.

Working on the UltraRAM project, I grasped the immense importance of iterative feedback loops in product development. Just as Jakub Barciński highlighted, constant engagement with potential customers and industry experts became pivotal in refining our vision. Inventing and ideating was one side of the coin, but ensuring that our innovations had tangible real-world value was the other. It's one thing to have an idea, and entirely another to mould it in a way that resonates with the needs of the market and the demands of feasibility.

Additionally, much like Javier Páez Franco, I too recognized the indispensable power of dreaming big. But more than that, it was about framing those dreams in actionable terms. The emissions' data comparison and its stark reality was a testament to the immense potential technology holds, and the responsibility that comes with it.

Collaborating with diverse minds was another highlight. The richness of different perspectives, backgrounds, and experiences not only enhanced our project but also enriched my personal growth. It underscored the value of diverse thought in challenging and redefining preconceived notions.

In conclusion, the CERN HPD Summer School was not just an educational endeavour but a holistic journey. From understanding the depths of AI and its implications to the hands-on experience with ULTRA-RAM, it was a confluence of learning, innovation, and self-discovery.

Javier Páez Franco:

The CERN HPD Summer School provided invaluable insights, teaching me to aspire for ambitious goals to uncover technology's true potential. First, the opportunity to work at CERN, a place I always dreamed of visiting. Next, joining a multidisciplinary team for the first time was a delightful experience, as the team's immediate chemistry made the journey even more enjoyable.

Additionally, I learnt about the necessity of dreaming big, in order to find those applications that our technology can really solve, and the importance of the balance between innovation and market value, such as the UltraStick idea. Furthermore, I discovered the power of prototyping, a practice I hadn't explored before. It was the perfect tool to visualize, refine, and test our ideas. Besides, I realized the significance of seeking expert validation for our business ideas, though I wish we had more time for complete outreach.

Overall, the CERN HPD Summer School was an extraordinary platform to learn about idea generation, validation, and prototyping. Interacting with outstanding individuals from diverse backgrounds significantly enriched my creative process, making it an unforgettable event.

Miłosz Pluciński:

CERN IdeaSquare first taught me that technology and society are intertwined, which made a clear distinction in my head between invention and innovation. Also, I learned to look critically at my own and my team's ideas, and I realized the importance of feedback from other people.

I think, similarly to my teammates, that dreaming big is definitely a more realistic approach for me after the CERN IdeaSquare Summer School, especially coming from a country where dreaming big (for example, the start-up culture in the U.S.) is mocked like nowhere else. It was quite hard to really believe in the idea we were pursuing, but I think that the CERN IdeaSquare Summer School helped me believe in the innovation I could not have imagined happening before.

Overall, I think that the CERN HPD Summer School not only changed my threshold of what I consider "realistic," but my biggest lesson from the Summer School was the extent of the impact a conversation with friends or experts can have. Before the Summer School, I would never have believed that this sort of conversation would give me greater insight than reading scientific articles or forum threads.