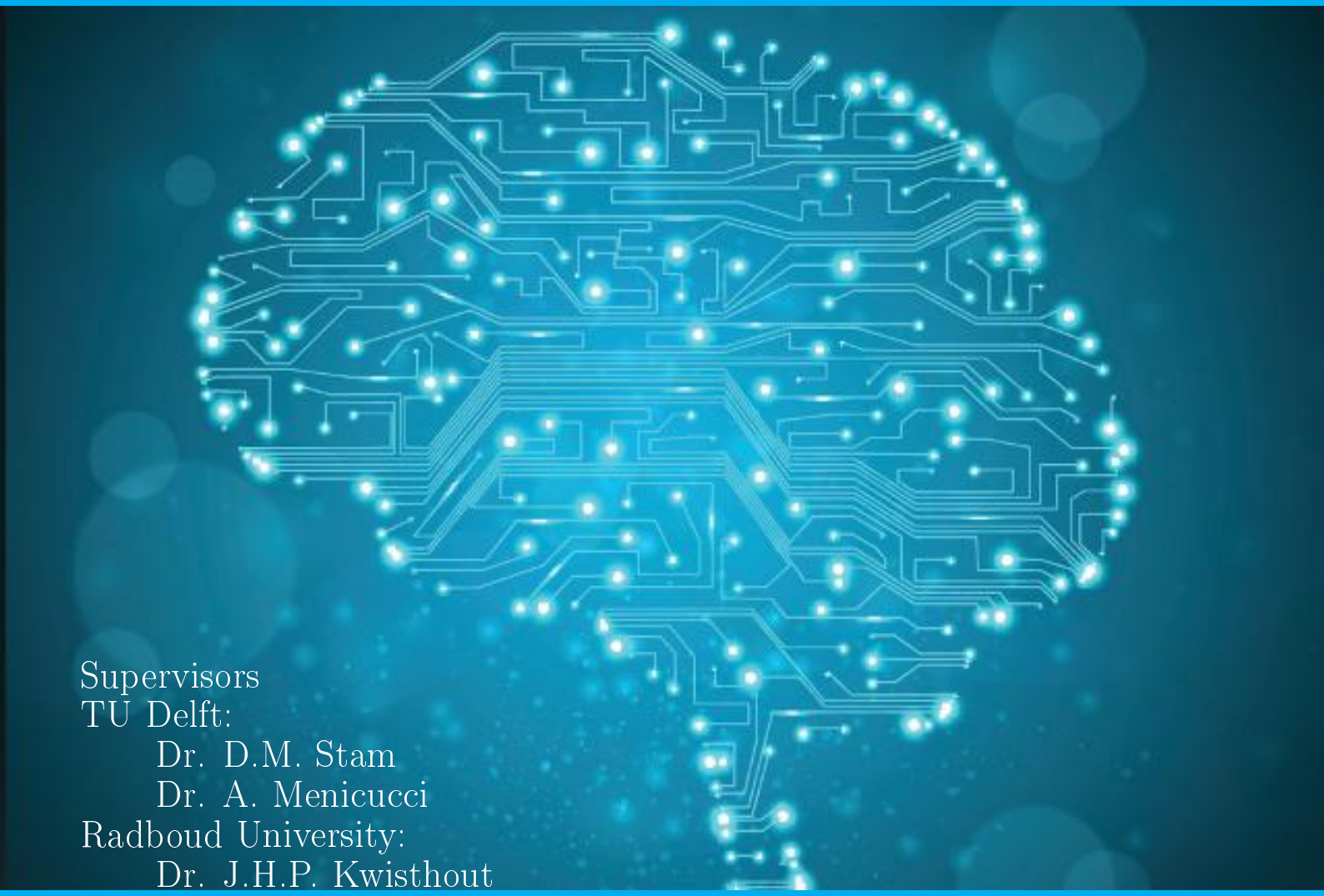
Leveraging brain adaptation to increase radiation resistance of neuromorphic space hardware

AE5810 Thesis Project: baseline report

Akke Toeter



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TU Delft

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AE5810 Thesis Project: baseline report

by

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Systems Engineering component of the AE5810 Thesis
at the Delft University of Technology.

Student number: 1507958
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TU Delft

Contents

Chapter 1

Introduction

This document presents the baseline for the AE5810 Thesis Project of the Space Flight Master at the Faculty of Aerospace Engineering of Delft University of Technology and the SOW-MKI92 Research Project of the Master in Artificial Intelligence at the faculty of Social Sciences of Radboud University. Its purpose is to identify the 2-5 most feasible design options that can be used to determine whether the principle of brain adaptation can be leveraged in neuromorphic space hardware.

The baseline report presents the Functional Flow Diagram (FFD) and Functional Break-down Diagram (FBD) in chapter 2 and chapter 3 respectively. These function descriptions of the system that is to be designed, is then used to generate the Requirements Discovery Tree (RDT) in chapter 4. Next, the resource allocation and budget breakdown presented in chapter 5. This is followed by the technical risk assessment in chapter 6. From the RDT, the Design Options Structuring Tree (DOT) is generated in chapter 4. Contingency management is applied in chapter 8. A market analysis is presented in chapter 9, and the sustainable development strategy is presented in chapter 10. To ensure this work is performed with sufficient quality, the reporting and quality control is presented in chapter 11. The baseline is concluded in chapter 12.

Chapter 2

Functional Flow Diagram

To gain insight in the system that is to be designed, a Functional Flow Diagram is generated. This FFD presents the high level functions that the system should be able to perform, in chronological order. These functions are presented in the flow diagram of **??**.

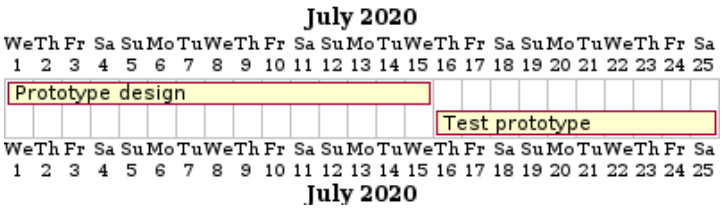

Figure 2.1: A functional flow diagram with the high-level functions of the system that is to be designed.

1. Initialise & start space-related function on neuromorphic architecture without brain adaptation implementation.
2. Initialise & start space-related function on neuromorphic architecture with brain adaptation implementation.
3. Endure modelled space radiation on neuromorphic architecture.
4. Measure space-related function performance without brain adaptation implementation.
5. Measure space-related function performance with brain adaptation implementation.
6. Report any performance difference between with- and without brain adaptation.
7. Determine significance of difference.

From these high level functions, a more detailed functional breakdown diagram is generated.

2.1. Detailed Functional Flow Diagram

1. Initialise & start space-related function on neuromorphic architecture without brain adaptation implementation.
   (a) Boot/initialise neuromorphic architecture
   (b) Load function.
   (c) Load function data.
2. Initialise & start space-related function on neuromorphic architecture with brain adaptation implementation.
   (a) Boot/initialise neuromorphic architecture

   (b) Load brain adaptation.
   (c) Load space-related function.
   (d) Load space-related function data.

3. Render and endure modelled space radiation on neuromorphic architecture.
   (a) Determine simulated space radiation pattern of neuromorphic space architecture.
   (b) Expose neuromorphic architecture to simulated space radiation pattern.
   (c) Complete space-related function.
   (d) Return results of space-related performance.

4. Measure space-related function performance without brain adaptation implementation.
   (a) Retrieve space-related function output.
   (b) Convert space-related function output to score.

5. Measure space-related function performance with brain adaptation implementation.

6. (a) Retrieve space-related function output.
   (b) Convert space-related function output to score.

7. Report difference between the scores of the architectures with- and without brain adaptation.

8. Determine significance of difference.

2.1.1. Description

1. Initialise & start space-related function on neuromorphic architecture without brain adaptation implementation.
   - To run a function on the neuromorphic architecture, it will have to be booted and initialised. The function that will be ran on the neuromorphic architecture is space related, to increase the level of representativeness of this study, in terms of space applications. The initalisation allows for loading the space related function that is to be executed. Additionally, the space related function may require (training) data on which it is ran. For example, a Martian rover that has a function that identifies rocks in its environment, may be partially simulated by loading a (labelled) dataset of Martian images.

     To run the function without brain adaptation implementation, allows for the creation of a baseline to which the brain adaptation performance can be compared.

2. Initialise & start space-related function on neuromorphic architecture with brain adaptation implementation.
   - The intialisation of the brain adaptation implementation can occur, before, during or after the loading of the space related function. Which of these options is selected depends on the more detailed design process.

3. Endure modelled space radiation on neuromorphic architecture.
   - The radiation robustness of the neuromorphic architecture can be tested by exposing the neuromorphic architecture to the radiation that it would experience in a space application. To determine what this radiation is, a relevant space mission and space function are selected. The time, position and orientation of the spacecraft in such a mission is then used to derive the radiation pattern to which the radiation may be exposed. This radiation is pattern is then used to determine to which (simulated) radiation the neuromorphic architecture will be exposed.

4. Measure space-related function performance without brain adaptation implementation.

- The performance of the space related function without brain adaptation implementaiton on the neuromorphic architecture is measured before, during and/or after radiation exposure. Which of these measuring moments are used, is still to be determined by the detailed design process. This measurement then serves as a comparison baseline to put the impact of the brain adaptation implementation into context.

5. Measure space-related function performance with brain adaptation implementation.

6. - Once a baseline for comparison is established, the space related function can be ran again on the neuromorphic hardware, whilst being exposed to radiation. In this second setting, the brain adaptation implementation is used in an attempt to increase the radiation robustness of the neuromorphic architecture. The performance of the space related function is then measured before, during and/or after radiation exposure. Which of these measuring moments are used, is still to be determined by the detailed design process.

7. Report any performance difference between with- and without brain adaptation.

8. - If any performance difference is observed between the space related function with- and without brain adaptation implementation, it will be computed and stored.

9. Determine significance of difference.

10. - An analysis is performed to determine the level of significance of any observed difference.

Chapter 3

Functional Breakdown Diagram

This section presents the functional breakdown diagram of the system that is designed in this thesis project. This FBD is generated using the detailed functional flow diagram of section 2.1. The FBD presents the activities in an hierarchical style.

1. Run space-related function on neuromorphic architecture.
    (a) Initialise neuromorphic architecture.
    (b) Optional: Load brain adaptation implementation.
    (c) Load space related function.
    (d) Load space related function data.
    (e) Run space related function.
    (f) Complete running space related function.
    (g) Retrieve space related function outputs.
    (h) Convert space related function outputs to performance score.
    (i) Report difference between the scores of the architectures with- and without brain adaptation.
    (j) Determine significance of difference.
2. Render and endure modelled space radiation on neuromorphic architecture.
    (a) Generate simulated space radiation pattern of neuromorphic space architecture.
    (b) Expose neuromorphic architecture to simulated space radiation pattern.
    (c) Optional: model architecture-radiation interaction.
    (d) Optional: measure architecture-radiation interaction.

Chapter 4

Requirements Discovery Tree

This section presents an overview of the requirements that are identified within this thesis project. Its purpose consists of listing the requirements that drive the design, identifying killer requirements and presenting an overview of the project requirements. section 4.1 contains the mission need statement of this project. Next, the stakeholder requirements are identified in section 4.2. The top level requirements are presented in section 4.3, and the key requirements are presented in section 4.4. From these combined requirements, the Requirements Discovery Tree is drafted in section 4.5.

4.1. Mission Need Statement

The mission need statement is generated in the project plan phase, and is included in this section again to provide the context of the requirement derivation process. The MSN is:

Increase the radiation robustness of neuromorphic space hardware by leveraging the principle of brain adaptation in neuromorphic hardware.

4.2. Stakeholder Requirements

The following stakeholder requirements are identified:

- **STKH-UNI-01** - The research that is performed shall be reproducible.
- **STKH-UNI-02** - The sustainability of the design concepts shall be taken into account in the design trade-off process.
- **STKH-SPACEBRAINS-01** - Achieve results towards the REACH research by Q2 2022.
- **STKH-SPACEBRAINS-01-a** - Achieve results towards the REACH research by either: 2022-03-01, 2022-04-07, 2022-07-01.
- **STKH-ICONS-01** - Submit paper documenting research results before April 15th, 2022.
- **STKH-ICONS-01-a** - Submit full paper of 6-8 pages, presenting original research, or submit short paper of 3-4 pages that has preliminary results.
- **STKH-ICONS-02** - Upon acceptance for a presentation, submit presentation before July 27th, 2022.
- **STKH-RADBOUD-01** - The research proceedings shall be documented and submitted in a format accepted by Dr. J.H.P. Kwisthout before the SOW-MKI92 Research Project is completed.
- **STKH-RADBOUD-02** - The research for the SOW-MKI92 Research Project shall be performed using at least 28 EC of work.
- **STKH-Delft-01** - The research proceedings shall be documented and submitted in a format accepted by Dr. D.M. Stam and Dr. A. Menicucci before the AE5810 Thesis Project is completed.
- **STKH-Delft-02** - The research for the AE5810 Thesis Project shall be performed using at least 42 EC of work.

4.3. Top Level Requirements

The following requirements for this thesis project are identified:

- **TECH-01** - Technology Readiness Level (TRL) of the used technology shall be at least TRL 4 [-].
- **TEST-01** - Radiation robustness shall be tested in terms of algorithmic performance.
- **TEST-02** - The radiation tests shall be technically and economically feasible.
- **TEST-03** - The radiation tests results shall be generated before September 2022.
- **SUS-01** - Sustainability management shall be integrated in each phase of this project.
- **SUS-02** - Sustainability shall be assessed in the design trade-off process.
- **SAF-01** - All participants involved in testing, integrating and operations shall not be exposed to serious danger.
- **ESA-01** - Throughout this project quarterly reports shall be provided to the SpaceBrains foundation and the European Space Agency (ESA).

4.4. Identification Key Requirements

The key requirements are requirements that can render the project infeasible, requirements that drive the design, and/or requirements that induce high risk to project success. Within this thesis project, the following key requirements are identified:

1. **STKH-SPACEBRAINS-01** - Achieve results towards the REACH research by Q2 2022.
2. **TECH-01** - Technology Readiness Level (TRL) of the used technology shall be at least TRL 4 [-].
3. **TEST-03** - The radiation tests results shall be generated before September 2022.

The **STKH-SPACEBRAINS-01** requirement significantly drives the design space, as physical radiation tests are not deemed feasible within the given timeframe and project constraints. **TEST-03** implies a strict time constraint that induces significant risk to project success as it limits the amount of time available for development and scheduling. **TECH-01** significantly drives the design as it limits the design space to concepts that rely only on technologies of TRL 4 and higher.

4.5. Requirements Discovery Tree

A requirements' discovery tree is currently omitted due to time constraints.

Chapter 5

Resource Allocation and Budget Breakdown

Chapter 6

Technical Risk assessment

Chapter 7

Design Option Structuring Tree

The purpose of the design option tree is to find a feasible design option that can satisfy the requirements. This selection process can be an iterative process in case no feasible design option is found in the initial design option tree. By positioning the design options in a tree format, their hierarchical structure becomes visible. The tree is structured such that the most impactful decisions are selected at the top of the tree, whereas more detailed decisions are made at lower levels of the tree. Several subsections are created to Figure 7.2 presents the design option tree for this thesis. The nodes in the tree represent design options and child leafs represent design options within a parent design option. For example, a choice may be made to use digital neuromorphic hardware, and within that design space, a particular chip may be selected. Multiple (parallel) design options may be selected. For example, a softwarematic and hardwarematic implementation may be chosen.

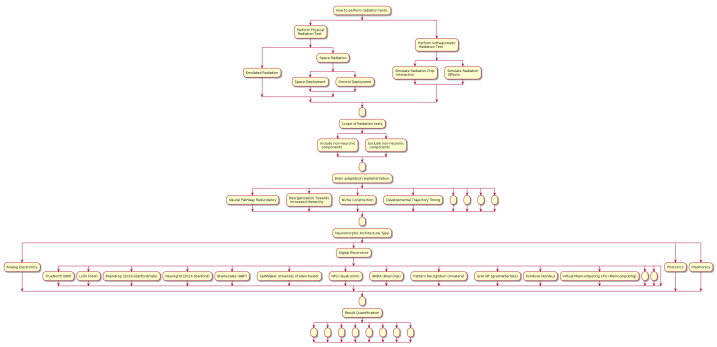

Figure 7.1: A functional flow diagram with the high-level functions of the system that is to be designed.

7.1. Pruning

With the design option tree generated, it can be pruned of options that are considered infeasible. This is done using the knowledge base that was generated in the literature study and using the requirements identified in chapter 4. The pruning process will be performed from top to bottom, which matches from high- to low hierarchical design choices.

7.1.1. Tested Functionality

At the time of writing, no specific function that is used for testing, can be eliminated.

7.1.2. How To Perform Radiation Tests

1. Starting with key requirement: **STKH-SPACEBRAINS-01** and **STKH-ICONS-01**, it is possible to eliminate the physical radiation test design option(along with its children), before the ICONS deadline of April 15th, 2022. Given the full scope of the thesis, and the **TEST-03** requirement which implies a test deadline before September 2022, a physical radiation test is still considered feasible before that time. Hence, instead of a complete termination (red), it is turned orange.

2. Continuing with the **STKH-SPACEBRAINS-01** requirement, it is considered infeasible to do a full simulation of radiation effects on the hardware components, before the ICONS deadline of April 15th, 2022. Hence, also this option will be coloured orange. Most neuromorphic chips in the DOT are proprietary, with many of the chip designs not being publically available. Since that makes it difficult to determine what the radiation effects will be on the hardware components of the chip, and how those effects, such as single-event upsets, would propagate towards influencing neurons and/or synapses. Therefore, this option is not considered feasible before April 15th 2022. It may be possible to contact manufacturers to ask how the radiation influences the neuronal- and synaptic properties. If such research is performed, it may be applied to simulate the neuromorphic hardware-radiation interaction softwarematically with sufficient accuracy to produce meaningful results.

7.1.3. Scope Of Radiation Tests

1. For the same as the last enumerated point of section 7.1.2, including the non-neuromorphic components is not considered feasible for before the ICONS deadline of April 15th, 2022. Hence, this element is also coloured orange.

7.1.4. Brain Adaptation Implementation

At the time of writing, no brain adaptation mechanisms can be eliminated.

7.1.5. Neuroplasticity Mechanism

At the time of writing, no neuroplasticitiy mechanisms can be eliminated.

7.1.6. Neuromorphic Architecture

1. Some neuromorphic architectures can be eliminated based on logistical reasons. Currently, the only direct access within this thesis project is to the Loihi. Furthermore, it may be expected that access to Pattern Recognition Chip by Innaterra may be realised after the ICONS deadline. Similarly, the Spinnaker device may become available later-on in the project. An economic feasibility assessment needs to be made on whether they should be used in physical radiation testing or not.

2. Some of the neuromorphic chip manufacturers have been contacted in the past, these contacts may allow for access to their respective chips for physical radation testing, if the intermediate results at ICONS are promising. Hence, they are kept orange.

7.1.7. Result Quantification

1. Since physical radiation testing is not deamed possible, and since the hardware diagrams of the respective neuromorphic architectures are not available, it is not deemed feasible to include a radiation effect analysis before ICONS. Therefore, this option is turned orange.

7.1.8. Pruned Design Option Tree

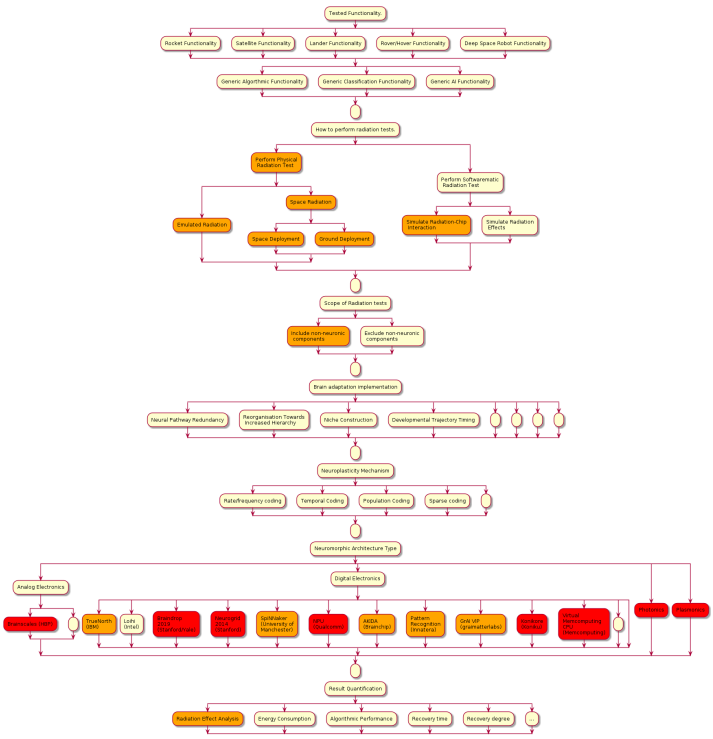

Figure 7.2: A functional flow diagram with the high-level functions of the system that is to be designed.

7.2. Preliminary Design Option Selection

With some design options eliminated, an analysis can be performed to see whether some design options are considered to be more feasible than others. This analysis is started by taking the **STKH-SPACEBRAINS-01** requirement into account, which implies results need to be produced by April 15th. This allows for expressing some design option preferences as listed in **??** to **??**. Taking the full scope of the thesis project into account allows identification of design options that seem most feasible for a follow-up with physical radiation testing.

7.2.1. Tested Functionality Preference

?? For performing a generic algorithmic functionality for the following two reasons:

1. No additional dependencies such as datasets, panda packages, tensorflow etc. is required. This lowers the probability of allocating time on work that does not directly support the objective of this thesis project.

2. No preprocessing work, such as loading and/or cropping images etc., is required. This increases the amount of time that can be allocated to implementing the brain adaptation and testing its functionality.

3. Graph algorithms are typically used in space applications [**?**].

4. Thorough testing can quickly be set up for graph algorithms.

7.2.2. How To Perform Radiation Tests Preference

?? Using softwarematic radiation tests that simulate radiation effects.

7.2.3. Scope of Radiation Tests Preference

?? Excluding non-neural components from radiation effects allows for a complete focus using the expected radiation effects on the neural and synaptic properties, without having to model additional radiation interactions with (other) hardware elements. This increases the feasibility of producing results by April 15th.

7.2.4. Brain Adaptation Implementation Preference
?? No preference in brain adaptation implementations is expressed at the time of writing.

7.2.5. Neuroplasticity Mechanism Preference
?? No preference in neuroplasticity mechanisms is expressed at the time of writing.

7.2.6. Neuromorphic Architecture Type Preference
?? Based on availability and previous experience, a preference is expressed for the Loihi platform for the softwarematic simulation. Insights from this simulation will be used to determine the best way forward towards hardware simulations. Since the Innatera chips are expected to be available for testing in the second quarter of 2022, combined with there relatively low cost, this option is mentioned as a possible suitable candidate for physical radiation testing. The Spinnaker boards appear to have a higher unit cost.

7.2.7. Result Quantification Preference
?? Based on the vicinity of the ICONS deadline of April 15th, 2022, a preference is expressed for measuring the softwarematic results in terms of algorithmic performance. This is because it forms the most direct measurement that can be used to determine whether the principle of brain adaptation is indeed able to increase the radiation robustness of neuromorphic space hardware.

7.2.8. Preliminary Design Option Tree
The preferences expressed in section 7.2 are coloured green in the preliminary design option tree visualised in fig. 7.3.

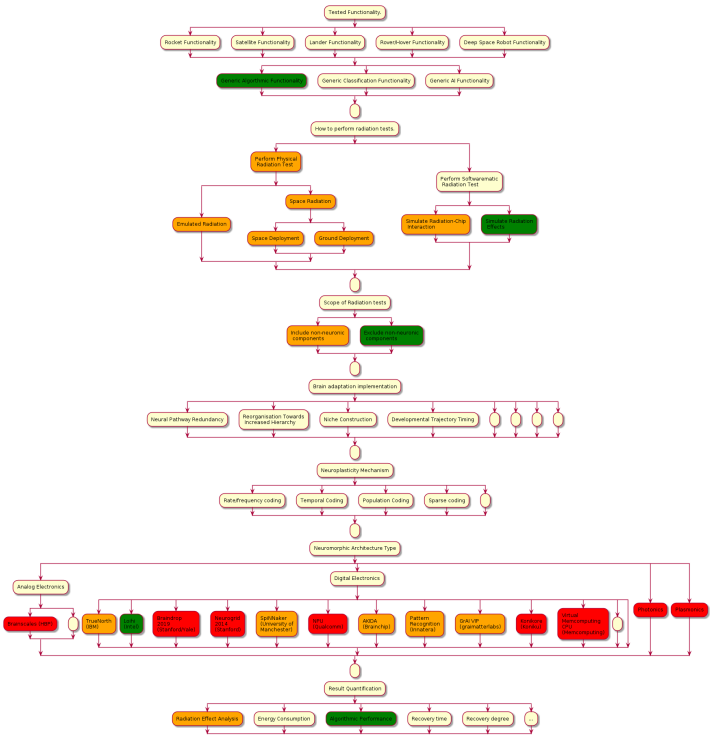

Figure 7.3: todo

7.3. Proposed Design options
To summarise, the following options are proposed to be executed during the midterm:

Chapter 8

Contingency Management

Chapter 9

Market Analysis

Chapter 10

Sustainable Development Management

Chapter 11

Reporting and Quality Control

The following quality control compliance checklist can currently be generated for this project plan:

- Language Tools Grammar check applied:✔
- Language Tools Spelling check applied:✔
- CI is ran on code base used in generating this Project Plan:✗
  - Python Black Formatting Compliance:✗
  - ShellCheck Compliance:✗
  - Latex Prettier Formatting Compliance:✗
  - Python Unit Test Passing: 2 failed, 7 passed [tests]
  - Python Test Coverage %:✗[%]
  - Shell Unit Test Passing:✗[tests]
  - Shell Unit Test Coverage %:✗[%]
- Manual Quality check:
  1. Citations still have to be compiled correctly.
  2. Reproduction instructions in Appendix A should be updated.
  3. Word wrap should be applied to .uml appendices.

Chapter 12

Conclusion

Acronyms

ALU Arithmatic Logic Unit. 30

ANN Artificial Neural Network. 30

BIOS Basic Input/Output System. 30

BISER Built-in Soft Error Resillience. 30

BIT Binary Digit. 30

BJT Bipolar Junction Transistor. 30

CME Coronal Mass Ejection. 30

CMOS Complementary MetalâĂŞOxideâĂŞSemiconductor. 30

CPU Central Processing Unit. 30

DEC Double-error Correcting Code. 30

DICE Dual Interlocked Storage Cell. 30

DNN Deep Neural Network. 30

DNU Dual-node Upset. 30

DOD Department of Defence. 30

DOT Design Options Structuring Tree. 3, 18, 30

DRAM Dynamic Random Access Memory. 30

ECC Error Correction Code. 30

ELT Enclosed Layout Transistor. 30

ESA European Space Agency. 12, 30

FBD Functional Break-down Diagram. 3, 9, 30

FET Field-Effect Transistor. 30

FFD Functional Flow Diagram. 3, 5, 30

GCD Greatest Common Divisor. 30

GCR Galactic Cosmic Ray. 30

IC Integrated Circuit. 30

INRC Intel Neuromorphic Research Community. 30

LCM Least Common Multiple. 30

LET Linear Energy Transfer. 30

MOS MetalâĂŞOxideâĂŞSemiconductor. 30

MOSFET MetalâĂŞOxideâĂŞSemiconductor Field-Effect Transistor. 30

MPNN Multilayer Perceptron Neural Network. 30

MSN Mission Need Statement. 11, 30

NVM Non-Volatile Memory. 30

POS Project Objective Statement. 30

RAM Random Access Memory. 30

RDT Requirements Discovery Tree. 3, 11, 30

ROM Read Only Memory. 30

SEC Single-error Correcting Code. 30

SEE Single-event Effects. 30

SEGR Single-event Gate Rupture. 30

SEIB Single-event Induced Burnout. 30

SEL Single-event Latch-up. 30

SER Soft-error Rate. 30

SERL Soft-error Resilient Latch. 30

SES Single-event Snapback. 30

SET Single-event Transient. 30

SEU Single-event Upset. 30

SNN Spiking Neural Network. 30

SNU Single-node Upset. 30

SPE Solar Particle Events. 30

SPENVIS Space Environment Information System. 30

SRAM Static Random Access Memory. 30

STDP Spike-Timing-Dependent Plasticity. 30

TLB Translation Lookaside Buffer. 30

TMR Tripple-mode Redundancy. 30

VLSI Very-Large-Scale Integration. 30

WBS Work Break-down Structure. 30

WFD Work Flow Diagram. 30

Glossary

(electron) holes In the context of doped semiconductors, holes are positions where electron acceptors are located, in other words, they are holes at which the electron can go.. 30

CPU cache A small hardware memory unit that is faster than the main memory and closer to the Arithmatic Logic Unit.. 30

data cache A cache that is designed to increase the speed with which data is fetched and stored.. 30

formula A mathematical expression. 30

instruction cache A cache that is designed to increase the speed with which instructions are fetched.. 30

latex Is a mark up language specially suited for scientific documents. 30

mathematics Mathematics is what mathematicians do. 30

memory cell A fundamental/basic unit in computing that is used to store information.. 30

n-type semiconductor A semiconductor that is doped with electron donors. 30

p-n junction A boundary interface of two a p-type semiconductor and a n-type semiconductor. 30

p-type semiconductor A semiconductor that is doped with electron acceptors. 30

primary memory A form of memory that is only accessible to the Central Processing Unit which reads instructions from it and executes those instructions.. 30

prompt charge The charge that is collected by means of funnelling.. 30

random-access A memory type that has access times that are independent of its physical location.. 30

unipolar transistors Unipolar transistors are transistors that use either electrons or electron holes as charge carriers and not the combination of the two.. 30

Nomenclature

c	Speed of light in a vacuum inertial frame
h	Planck constant

.1. Appendix

For transparency the source code for the generated Gantt chart is included. To recreate the Gantt chart, first install the package diagrams in a python 3.6,3.7 or 3.8 environment. One can do this in Anaconda prompt by opening it and entering:

```
conda update -n base -c defaults conda
conda create -n py36 python=3.6
conda activate py36
pip install diagrams
pip install plantuml
```

An individual Gantt chart diagram can be generated by browsing in anaconda to the direction of the `<diagram name>.txt` file, and processing it with command `python -m plantuml <diagram name>.txt`. However, one can also automatically (re-)generate all the diagrams encoded in the `.txt` files in the `../../code/project3/Diagrams/` folder by opening Anaconda prompt, browsing to the directory of `../../code/project3/` and running: `python create_diagrams.py`. The code of `python create_diagrams.py` is included in **??**, and to enable people with visual impairments to read the diagrams, the source codes of the diagrams are included in **??**. Additional example graphs and graph generation syntax is specified in: `https://plantuml.com/wbs-diagram`.

.2. Source Code of Flow Diagrams

The code of the Gantt chart that contains the project planning, is listed as:

gantt.uml

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project starts the 2021/11-22
saturday are closed
sunday are closed
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[<size:30>Gantt Chart - Final Phase - 0.2.5.3] as [0_2_5_3] lasts 35 days
[<size:30>Phase Finalisation - 0.3] as [0_3] lasts 5 days
[<size:30>Project Plan: Documentation And Quality Control - 0.3.0] as [0_3_0] lasts 1 days
[<size:30>Deliverable: Project Plan Report Draft - 0.3.1] as [0_3_1] happens at [0_3_0]'s end
[<size:30>Deliverable: Project Plan Review Presentation - 0.3.2] as [0_3_2] lasts 1 days
[<size:30>Process Project Plan Review Feedback - 0.3.3] as [0_3_3] lasts 1 days
[<size:30>Deliverable: Project Plan Report - 0.3.4] as [0_3_4] happens at [0_3_3]'s end

[<size:30>Baseline Review - 1] as [1] lasts 20 days
[<size:30>Function Specification And Requirement Generation - 1.0] as [1_0] lasts 4 days
[<size:30>Functional Flow Diagram - 1.0.1] as [1_0_1] lasts 1 days
[<size:30>Functional Breakdown Structure - 1.0.2] as [1_0_2] lasts 1 days
[<size:30>Determining Key Requirements - 1.0.3] as [1_0_3] lasts 1 days
[<size:30>Requirements Discovery Tree - 1.0.4] as [1_0_4] lasts 1 days
[<size:30>System Analysis - 1.2] as [1_2] lasts 10 days
[<size:30>Resource Allocation and Budget Breakdown - 1.2.0] as [1_2_0] lasts 1 days
[<size:30>Cost Breakdown Structure - 1.2.1] as [1_2_1] lasts 1 days
[<size:30>Market Analysis - 1.2.2] as [1_2_2] lasts 1 days
[<size:30>Scheduled Risk Assessment - 1.2.3] as [1_2_3] lasts 4 days
[<size:30>Technical Risk Assessment - 1.2.3.0] as [1_2_3_0] lasts 1 days
[<size:30>Radiation Test Facility Planning - 1.2.3.1] as [1_2_3_1] lasts 2 days
[<size:30>Contingency Management - 1.2.3.2] as [1_2_3_2] lasts 1 days
[<size:30>Scheduled Sustainability Assessment - 1.2.4] as [1_2_4] lasts 1 days
[<size:30>Verification And Validation Assessment Planning - 1.2.5] as [1_2_5] lasts 1 days
[<size:30>Finalizing Project Requirements - 1.2.6] as [1_2_6] lasts 1 days
[<size:30>Concept Generation - 1.3] as [1_3] lasts 2 days
[<size:30>High-level System Design Generation - 1.3.0] as [1_3_0] lasts 1 days
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[<size:30>System-level Design Option Tree - 1.3.0.0] as [1_3_0_0] lasts 1 days
[<size:30>Preliminary Unfeasible Concept Elimination - 1.3.0.1] as [1_3_0_1] lasts 1 days
[<size:30>High-level Subsystem Design Generation - 1.3.1] as [1_3_1] lasts 1 days
[<size:30>Subsystem-level Design Option Tree - 1.3.1.0] as [1_3_1_0] lasts 1 days
[<size:30>Phase Finalisation - 1.4] as [1_4] lasts 4 days
[<size:30>Baseline: Documentation And Quality Control - 1.4.0] as [1_4_0] lasts 1 days
[<size:30>Deliverable: Baseline Report Draft - 1.4.1] as [1_4_1] happens at [1_4]'s start
[<size:30>Deliverable: Baseline Review Presentation - 1.4.2] as [1_4_2] lasts 1 days
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[<size:30>Midterm Review Phase - 2] as [2] lasts 28 days
[<size:30>Preliminary Concept Selection - 2.0] as [2_0] lasts 1 days
[<size:30>Selected Concepts Design - 2.1] as [2_1] lasts 19 days
[<size:30>Simulated Space Application Design - 2.1.0] as [2_1_0] lasts 1 days
[<size:30>Neuromorphic Architectures Configurations - 2.1.1] as [2_1_1] lasts 1 days
[<size:30>Brain Adaptation Implementations - 2.1.2] as [2_1_2] lasts 1 days
[<size:30>Radiation Test Procedure Design - 2.1.3] as [2_1_3] lasts 1 days
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[<size:30>Performance Analysis - 2.1.6] as [2_1_6] lasts 4 days
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[<size:30>Radiation Characteristics - 2.1.6.0.0] as [2_1_6_0_0] lasts 1 days
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[<size:30>Function Performance Measurement Method - 2.1.6.0.2] as [2_1_6_0_2] lasts 1 days
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[<size:30>Sustainability Analysis - 2.1.11] as [2_1_11] lasts 1 days
[<size:30>Concepts System Sensitivity Analysis - 2.1.12] as [2_1_12] lasts 2 days
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[<size:30>Process Midterm Review Feedback - 2.3.3] as [2_3_3] lasts 1 days
[<size:30>Deliverable: Midterm Report - 2.3.4] as [2_3_4] happens at [2_3_3]'s end

[<size:30>Final Review Work Package - 3] as [3] lasts 73 days
[<size:30>Finalise Final Concept - 3.0] as [3_0] lasts 1 days
[<size:30>System Development - 3.1] as [3_1] lasts 39 days
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[<size:30>Electrical - 3.1.7] as [3_1_7] lasts 4 days
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[<size:30>Risk Analysis - 3.2] as [3_2] lasts 1 days
[<size:30>Sustainability Analysis - 3.3] as [3_3] lasts 1 days
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[<size:30>Buffer - 3.4] as [3_4] lasts 20 days
[<size:30>Define Technical Challenges - 3.4.0] as [3_4_0] lasts 10 days
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[<size:30>Final: Documentation And Quality Control - 3.8] as [3_8] lasts 3 days

[<size:30>Final Review Work Package 8: Orbit Radiation Simulation Of Adaptive Neuromorphic Architectures - 4] as [4] lasts 32 d
[<size:30>Perform Radiation Testing/Simulation - 4.0] as [4_0] lasts 7 days
[<size:30>Perform Orbit Radiation Simulation - 4.0.0] as [4_0_0] lasts 5 days
[<size:30>Store Simulation Results - 4.0.1] as [4_0_1] lasts 2 days
[<size:30>Analyse Experiment Results - 4.1] as [4_1] lasts 12 days
[<size:30>Document Research Results - 4.2] as [4_2] lasts 12 days
[<size:30>Green Light Review - 4.3] as [4_3] lasts 1 days

[<size:30>Delivery And Project Close Out Work Package 9 - 5] as [5] lasts 8 days
[<size:30>Document Tools - 5.0] as [5_0] lasts 1 days
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[<size:30>Document Design And Analysis - 5.2] as [5_2] lasts 1 days
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[<size:30>Future Recommendations - 5.4] as [5_4] lasts 1 days
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[<size:30>Deliverable: Final Review Presentation - 5.6] as [5_6] lasts 1 days
[<size:30>Process Final Review Feedback - 5.7] as [5_7] lasts 1 days
[<size:30>Deliverable: Final Report - 5.8] as [5_8] happens at [5_7]'s end

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'[Project Plan]  takes: 440[days] equating to:3520[hours] and costs: 20 per hour, yielding activity costs: 70400 Euros.
'[Project Introduction]  takes: 24[days] equating to:192[hours] and costs: 20 per hour, yielding activity costs: 3840 Euros.
'[The Global Picture]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Top Level Requirements]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Mission Need Statement]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Project Objective Statement]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euro
'[Team Organisation]  takes: 16[days] equating to:128[hours] and costs: 20 per hour, yielding activity costs: 2560 Euros.
'[Thesis Kick-off Meeting]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
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'[Organogram]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Project Procedures]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Communication Strategy]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Eu
'[Documentation And Quality Control Procedure]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding ac
'[Project Planning]  takes: 360[days] equating to:2880[hours] and costs: 20 per hour, yielding activity costs: 57600 Eur
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'[WFD - Baseline Phase]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euro
'[WFD - Midterm Phase]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros
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'[Work Breakdown Structure]  takes: 32[days] equating to:256[hours] and costs: 20 per hour, yielding activity costs: 512
'[Project Sustainability Approach]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs
'[Sustainability Introduction And Motivation]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding act
'[Sustainability Procedures]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280
'[Sustainability Approach Planning]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity cost
'[Project Risk Assessment Plan]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1
'[Initial Risk Assessment]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 E
'[Initial Contingency Management]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs:
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'[Gantt Chart]  takes: 280[days] equating to:2240[hours] and costs: 20 per hour, yielding activity costs: 44800 Euros.
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'[Gantt Chart - Midterm Phase]  takes: 280[days] equating to:2240[hours] and costs: 20 per hour, yielding activity costs
'[Gantt Chart - Final Phase]  takes: 280[days] equating to:2240[hours] and costs: 20 per hour, yielding activity costs:
'[Phase Finalisation]  takes: 40[days] equating to:320[hours] and costs: 20 per hour, yielding activity costs: 6400 Euro
'[Project Plan: Documentation And Quality Control]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yieldin
'[Deliverable: Project Plan Report Draft]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activit
'[Deliverable: Project Plan Review Presentation]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding
'[Process Project Plan Review Feedback]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity
'[Deliverable: Project Plan Report]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity cost


'[Baseline Review]  takes: 160[days] equating to:1280[hours] and costs: 20 per hour, yielding activity costs: 25600 Euro
'[Function Specification And Requirement Generation]  takes: 32[days] equating to:256[hours] and costs: 20 per hour, yie
'[Requirement Negotiation/Supervisor Feedback]  takes: 1[days] equating to:8[hours] and costs: 20 per hour, yielding act
'[Functional Flow Diagram]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 E
'[Functional Breakdown Structure]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs:
'[Determining Key Requirements]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1
'[Requirements Discovery Tree]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 12
'[Literature Study Synthesis]  takes: 1[days] equating to:8[hours] and costs: 20 per hour, yielding activity costs: 160
'[System Analysis]  takes: 80[days] equating to:640[hours] and costs: 20 per hour, yielding activity costs: 12800 Euros.
'[Resource Allocation and Budget Breakdown]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activ
'[Cost Breakdown Structure]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280
'[Market Analysis]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Scheduled Risk Assessment]  takes: 32[days] equating to:256[hours] and costs: 20 per hour, yielding activity costs: 51
'[Technical Risk Assessment]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280
'[Radiation Test Facility Planning]  takes: 16[days] equating to:128[hours] and costs: 20 per hour, yielding activity co
'[Contingency Management]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Eu
'[Scheduled Sustainability Assessment]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity c
'[Verification And Validation Assessment Planning]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yieldin
'[Finalizing Project Requirements]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs
'[Concept Generation]  takes: 16[days] equating to:128[hours] and costs: 20 per hour, yielding activity costs: 2560 Euro
'[High-level System Design Generation]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity c
'[System-level Design Option Tree]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs
'[Preliminary Unfeasible Concept Elimination]  takes: 4[days] equating to:32[hours] and costs: 20 per hour, yielding act
'[High-level Subsystem Design Generation]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activit
'[Subsystem-level Design Option Tree]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity co
'[Phase Finalisation]  takes: 32[days] equating to:256[hours] and costs: 20 per hour, yielding activity costs: 5120 Euro
'[Baseline: Documentation And Quality Control]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding ac
'[Deliverable: Baseline Report Draft]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity co
'[Deliverable: Baseline Review Presentation]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding acti
'[Process Baseline Review Feedback]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity cost
'[Deliverable: Baseline Report]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1


'[Midterm Review Phase]  takes: 224[days] equating to:1792[hours] and costs: 20 per hour, yielding activity costs: 35840
'[Preliminary Concept Selection]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs:
'[Selected Concepts Design]  takes: 152[days] equating to:1216[hours] and costs: 20 per hour, yielding activity costs: 2
'[Simulated Space Application Design]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity co
'[Neuromorphic Architectures Configurations]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding acti
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'[Brain Adaptation Implementations]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280
'[Radiation Test Procedure Design]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280
'[Configuration/Layout]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[N2 Chart/Interface Definition]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Eu
'[Performance Analysis]  takes: 32[days] equating to:256[hours] and costs: 20 per hour, yielding activity costs: 5120 Euros.
'[Astrodynamic Characteristics]  takes: 24[days] equating to:192[hours] and costs: 20 per hour, yielding activity costs: 3840 E
'[Radiation Characteristics]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Simulated Functionality Performance]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1
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'[Neuromorphic Architecture Characteristics]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity co
'[Component Characteristics]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[SEEs Characteristics]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[SEE Quantification]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[SEE Propagation Modelling]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Neuronal Characteristics]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Operations And Logistics]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Concepts Production Plans]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Reliability, Availability, Manufacturability and Safety]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yieldi
'[Risk Analysis]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Sustainability Analysis]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Concepts System Sensitivity Analysis]  takes: 16[days] equating to:128[hours] and costs: 20 per hour, yielding activity costs
'[Verification And Validation Assessment Of Concepts]  takes: 24[days] equating to:192[hours] and costs: 20 per hour, yielding
'[Trade-off]  takes: 24[days] equating to:192[hours] and costs: 20 per hour, yielding activity costs: 3840 Euros.
'[Trade-off Methods]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Trade-off Criteria and Weight Factors]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs:
'[Perform Trade-off]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Select Concept]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
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'[Midterm: Documentation And Quality Control]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity c
'[Deliverable: Midterm Report Draft]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 128
'[Deliverable: Midterm Review Presentation]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity cos
'[Process Midterm Review Feedback]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280
'[Deliverable: Midterm Report]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euro


'[Final Review Work Package]  takes: 584[days] equating to:4672[hours] and costs: 20 per hour, yielding activity costs: 93440 E
'[Finalise Final Concept]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[System Development]  takes: 312[days] equating to:2496[hours] and costs: 20 per hour, yielding activity costs: 49920 Euros.
'[Configuration/Layout]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[N2 Chart/Interface Definition]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Eu
'[Simulated Space Application Development]  takes: 32[days] equating to:256[hours] and costs: 20 per hour, yielding activity co
'[Neuromorphic Architecture Configuration]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity cost
'[Architecture Performance Assessment Tool]  takes: 32[days] equating to:256[hours] and costs: 20 per hour, yielding activity c
'[Brain Adaption Implementation]  takes: 32[days] equating to:256[hours] and costs: 20 per hour, yielding activity costs: 5120
'[Radiation Test Setup]  takes: 32[days] equating to:256[hours] and costs: 20 per hour, yielding activity costs: 5120 Euros.
'[Orbit Simulation]  takes: 32[days] equating to:256[hours] and costs: 20 per hour, yielding activity costs: 5120 Euros.
'[Radiation Simulation]  takes: 32[days] equating to:256[hours] and costs: 20 per hour, yielding activity costs: 5120 Euros.
'[Radiation Testing Environment]  takes: 32[days] equating to:256[hours] and costs: 20 per hour, yielding activity costs: 5120
'[Electrical]  takes: 32[days] equating to:256[hours] and costs: 20 per hour, yielding activity costs: 5120 Euros.
'[Communication And Data Handling]  takes: 32[days] equating to:256[hours] and costs: 20 per hour, yielding activity costs: 512
'[Production Plan]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[RAMS]  takes: 32[days] equating to:256[hours] and costs: 20 per hour, yielding activity costs: 5120 Euros.
'[Operations]  takes: 32[days] equating to:256[hours] and costs: 20 per hour, yielding activity costs: 5120 Euros.
'[Subsystem Development]  takes: 32[days] equating to:256[hours] and costs: 20 per hour, yielding activity costs: 5120 Euros.
'[Risk Analysis]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Sustainability Analysis]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Buffer]  takes: 160[days] equating to:1280[hours] and costs: 20 per hour, yielding activity costs: 25600 Euros.
'[Define Technical Challenges]  takes: 80[days] equating to:640[hours] and costs: 20 per hour, yielding activity costs: 12800 E
'[Solve Technical Challenges]  takes: 80[days] equating to:640[hours] and costs: 20 per hour, yielding activity costs: 12800 Eu
'[System Creation]  takes: 32[days] equating to:256[hours] and costs: 20 per hour, yielding activity costs: 5120 Euros.
'[Production]  takes: 16[days] equating to:128[hours] and costs: 20 per hour, yielding activity costs: 2560 Euros.
'[Manufacturing]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Assembly]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Verification and Validation]  takes: 24[days] equating to:192[hours] and costs: 20 per hour, yielding activity costs: 3840 Eu
'[Compliance Matrix]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Final: Documentation And Quality Control]  takes: 24[days] equating to:192[hours] and costs: 20 per hour, yielding activity c


'[Final Review Work Package 8: Orbit Radiation Simulation Of Adaptive Neuromorphic Architectures]  takes: 256[days] equating to
'[Perform Radiation Testing/Simulation]  takes: 56[days] equating to:448[hours] and costs: 20 per hour, yielding activity costs
'[Perform Orbit Radiation Simulation]  takes: 40[days] equating to:320[hours] and costs: 20 per hour, yielding activity costs:
```

```
'[Store Simulation Results]  takes: 16[days] equating to:128[hours] and costs: 20 per hour, yielding activity costs: 256
'[Analyse Experiment Results]  takes: 96[days] equating to:768[hours] and costs: 20 per hour, yielding activity costs: 1
'[Document Research Results]  takes: 96[days] equating to:768[hours] and costs: 20 per hour, yielding activity costs: 15
'[Green Light Review]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.


'[Delivery And Project Close Out Work Package 9]  takes: 64[days] equating to:512[hours] and costs: 20 per hour, yieldir
'[Document Tools]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Document Tests]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Euros.
'[Document Design And Analysis]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1
'[Lessons Learnt Session]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Eu
'[Future Recommendations]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280 Eu
'[Deliverable: Final Report Draft]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs
'[Deliverable: Final Review Presentation]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activit
'[Process Final Review Feedback]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs:
'[Deliverable: Final Report]  takes: 8[days] equating to:64[hours] and costs: 20 per hour, yielding activity costs: 1280

@endgantt
```

.3. Source Code of Organogram

The code of the organogram presented in **??**, is listed as:

organogram.uml

```
@startuml
actor Dr._D._Stam
actor Dr._A._Menicucci
actor Dr._J.H.P._Kwisthout
actor Akke
actor Elia_Montanari
actor Nathalie_Dorval

ref over Dr._D._Stam : 1. TU Delft: Supervisor
Akke -> Dr._D._Stam : 2. Provides documents and progress updates.
Dr._D._Stam -> Akke  : 3. Provides guidance, feedback and assessment.

ref over Dr._A._Menicucci : 1. TU Delft: Supervisor
Akke -> Dr._A._Menicucci : 2. Provides documents and progress updates.
Dr._A._Menicucci -> Akke  : 3. Provides guidance, feedback and assessment.

ref over Dr._J.H.P._Kwisthout : 1. Radboud University: Supervisor
Akke -> Dr._J.H.P._Kwisthout : 2. Provides documents and progress updates.
Dr._J.H.P._Kwisthout -> Akke  : 3. Provides guidance, feedback and assessment.

ref over Akke : 4. Student TU Delft, Radboud University

ref over Elia_Montanari : 5. SpaceBrains Foundation, ESA, Coach/Supervisor
Akke -> Elia_Montanari : 2. Provides quarterly review updates.
Elia_Montanari -> Akke  : 3. Provides guidance, feedback and assessment.

ref over Nathalie_Dorval : 6. ESA, Coach/Supervisor
Akke -> Nathalie_Dorval : 2. Provides quarterly review updates.
Nathalie_Dorval -> Akke  : 3. Provides guidance, feedback and assessment.

@enduml
```