Neuromorphic computing

Narrative and organization

Long version

TOPSECTOR ICT
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1. Introduction

To further advance the neuromorphic computing (NC) field an organizational roadmap is needed

- The **Topsector ICT** has the mission to support businesses, government, and knowledge institutions in realizing innovations in and with ICT, thereby strengthening the international position of the Netherlands as a leading country. It does so by bringing together a broad spectrum of public and private stakeholders in innovation coalitions focused on Key Enabling Digital Technologies.

- **Neuromorphic computing is one of the 44 Key Enabling Technologies of the Netherlands**. It is not selected as a top10 technology but mentioned in of the updated National Technology Strategy (NTS) and part of the forthcoming Knowledge and Innovation Covenant 2024–2027 as a closely intertwined technology with AI and Data and Cybersecurity technologies, which are prioritized in the NTS.

- In 2024, **a core team of experts** from Radboud University, University of Groningen, Delft University of Technology, Eindhoven University of Technology, University of Twente, AMOLF, CWI and SURF published a **white paper**, providing insight in the necessity and potential of neuromorphic computing for the Netherlands.

- As a follow-up to the white paper, the neuromorphic computing core group collaborated with the Topsector ICT to pursue several **follow-up actions** recommended by the whitepaper. One of the ambitions of the core team beyond the white paper was to develop a roadmap for a collaborative effort towards future-proof energy-efficient computing.

- This report provides insight for and the elements of **an organizational roadmap** for the next 10-30 years. The aim is to further advance the field of neuromorphic computing. It was based upon insights from neuromorphic experts from academia, governments and companies (a complete list is included in appendix 1).

- A central part of this effort involves mapping out the **necessary organizational capacity, infrastructure, and (research) funding** to realise this goal. The roadmap should include a proposition for stakeholders and funders, along with a narrative outlining the potential contribution of neuromorphic computing to economic and societal challenges.

TNO (2023). Reassessment of key enabling technologies. | Knowledge and Innovation Agenda 2024-2027 (2024). Key Enabling Technologies. | Ministery of Economic Affairs (2024). National Technology Strategy. | Core team neuromorphic computing, powered by Topsector ICT (2024). Neuromorphic Computing in the Netherlands White Paper.

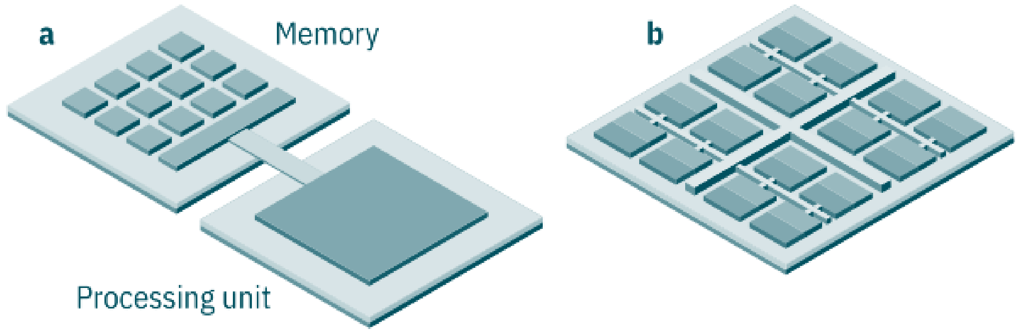
1. Introduction

Neuromorphic computing enables energy-efficient, secure and event-driven processing

- In the White Paper on Neuromorphic Computing, the concept of neuromorphic computing was introduced as **a promising new paradigm** rooted in the functioning of the human brain. As this roadmap builds on that foundation, we provide a brief summary here.

- Neuromorphic computing takes inspiration from the brain's remarkable ability to process information efficiently, using only about 20 watts of power, an almost negligible amount compared to the approximately 50 million watts consumed by today's supercomputers. **This efficiency arises from the brain's integrated architecture, where memory and processing occur in the same location.** Unlike traditional digital hardware, which separates memory and computation and which relies heavily on energy-intensive data transfer, neuromorphic systems aim to draw inspiration from the brain and use much less data transport.

- By mimicking the brain's structure, neuromorphic computing aims to enable **massively parallel, low-latency, and energy-efficient processing**. The core ambition is to replicate this efficiency and adaptability in brain-inspired systems. Not to copy the brain, but **to learn from its principles** to build fast, power-conscious, and intelligent machines.



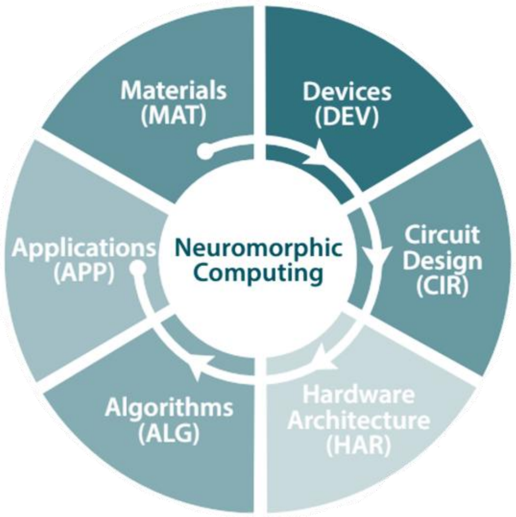
*Comparison between **a** traditional digital hardware and bottleneck between memory and processing unit and **b** neuromorphic chip architecture without this bottleneck. (M. Smolka et al., 2024).*

Core team neuromorphic computing, powered by Topsector ICT (2024). Neuromorphic Computing in the Netherlands White Paper.

1. Introduction

Brain-inspired computation must often be co-designed to achieve the desired performance

- In short: **neuromorphic computing refers to all hardware and software systems** - materials, devices, circuit designs, hardware architectures, algorithms and applications - that mimic to a significant extent the working principles of the biological brain consisting of neurons and synapses. Each layer plays a distinct role in enabling brain-inspired computation and must often be **co-designed** to achieve the desired efficiency and performance.



- **Materials:** New adaptive materials are needed to mimic synaptic behavior, unlike those used in conventional transistors.
- **Devices:** These components (e.g., switches, memories, artificial neurons) perform key functions such as signal transmission, storage, and sensing.
- **Circuit Designs:** Devices are combined into circuits that support event-driven, low-power operation and enable local learning.
- **Hardware Architectures:** These circuits are scaled into chips, either fully neuromorphic or hybrid, optimized for parallelism and sparse communication.
- **Algorithms:** Neuromorphic systems blur the line between hardware and software; they learn from data rather than being explicitly programmed.
- **Applications:** Ideal for specific tasks that are highly demanding in terms of data volume, response time, or energy constraints. This includes edge applications like pattern recognition and sensor fusion in domains such as robotics, health care, mobile payments, and agriculture. In addition to edge computing, neuromorphic systems are also relevant in cloud environments. Platforms such as Loihi and SpiNNcloud demonstrate how neuromorphic architectures can support massive parallelization, particularly for optimization problems that are difficult to scale efficiently on conventional digital systems.

Yole Développement (2021). Neuromorphic Computing and Sensing, Market and Technology report 2021. | Core team neuromorphic computing, powered by Topsector ICT (2024). Neuromorphic Computing in the Netherlands White Paper.

Impact potential of NC

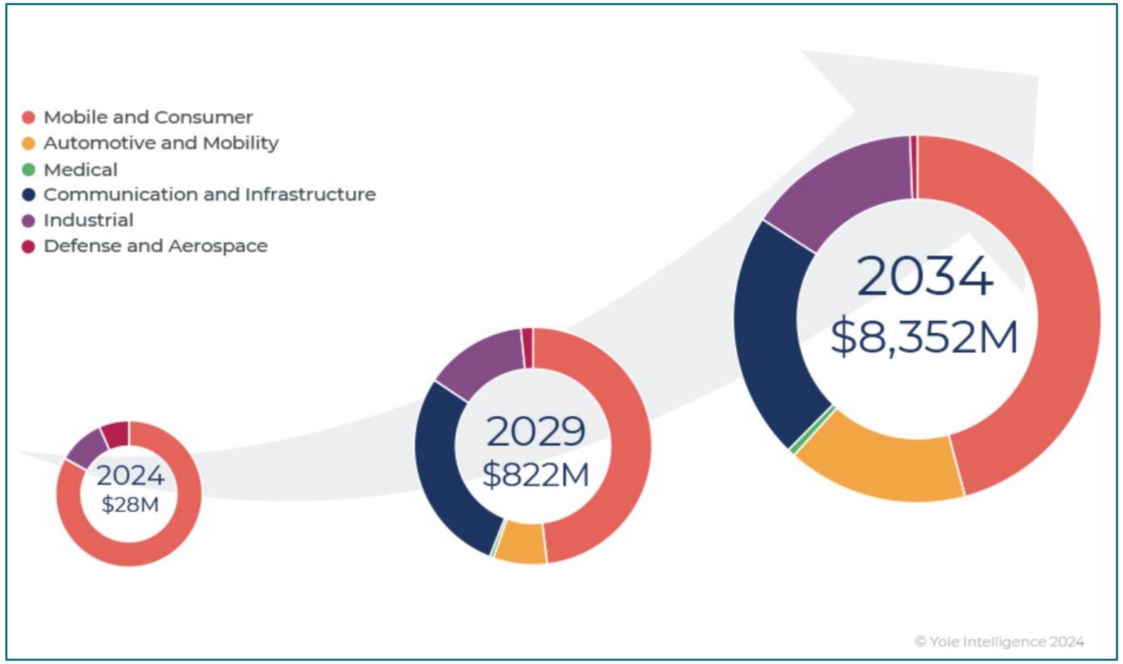
Overcoming shortcomings of conventional computing increases economical feasibility of NC

- Since around 2015, it became clear that traditional scaling by adding transistors and memory was nearing its limits. While many expected Moore's Law to end, conventional systems evolved in new ways, remaining relevant longer than anticipated. Scalable GPU systems drove the deep learning revolution, which renewed interest in new computing paradigms. This meant **the foundational technology on which computers are built continued to progress**.

- However, the fundamental performance **limits of conventional systems**, especially regarding energy consumption, persist and are becoming increasingly restrictive in the long term as AI models and workloads grow. This is illustrated by Amazon's recent announcement of a 2.2-gigawatt AI data center. At the same time, chip development costs continue to rise, decreasing the economical feasibility of scaling conventional (semicon) devices.

- Key assets of neuromorphic computing, such as energy efficiency, low latency and real time learning, have **the potential to resolve these bottlenecks**.

- The global neuromorphic market is small compared to conventional and quantum computing (the latter is 40 times larger) but is **projected to grow rapidly**, estimated at $8,352M by 2034. The largest share is expected in mobile & consumer, followed by communication & infrastructure (including data centers), automotive & mobility, and industrial. Defense, aerospace, and medical are also expected to contribute smaller shares.



Based on interviews with experts and key stakeholders in the neuromorphic field. | Yole Intelligence (2024). 2024-2034 Neuromorphic Sensing and Computing Forecast. To compare: The global quantum computing market size was valued at USD 885.4 million in 2023 and is projected to grow from USD 1,160.1 million in 2024 to USD 12,620.7 million by 2032, exhibiting a CAGR of 34.8% during the forecast period. Fortune business insights (2025). | The New York Times (2025). At Amazon's Biggest Data Center, Everything Is Supersized for A.I.

Neuromorphic computing has the potential to enhance, facilitate and optimize key leading technologies

- The National Technology Strategy ('Nationale Technologie Strategie', NTS) is a policy document of the Dutch government that will give direction to Dutch innovation policy in the coming years. The document identifies ten key technologies that are crucial for the Dutch economy, society and national security (in a changing geopolitical context) , and on which additional efforts will be made to maintain and expand technological leadership.

- According to the National Technology Strategy, the Netherlands have a leading position in ten technology areas. Of these ten, neuromorphic computing has the potential to contribute to optical systems and integrated photonics, quantum technologies, artificial intelligence and data science, cybersecurity technologies and semiconductor technologies, as shown on the right.

- Neuromorphic computing has the potential to enhance, facilitate and optimize key leading technologies, which is illustrated in the right. Neuromorphic computing is not a replacement of these technologies. It is here to strenghten their position. Thus, advancing **neuromorphic computing is of strategic importance for NTS**, and thereby for the Netherlands.

Optical Systems and integrated photonics: Enhances photonic computing by enabling sparse, asynchronous data processing, necessary for scalable optical AI systems.

Quantum technologies: Offers nonlinear, low-power, real-time inference needed to stabilize quantum systems and manage qubit states adaptively.

Artificial intelligence and data science: Scales AI beyond data centers to edge and embedded systems, in alignment with European AI goals around trustworthiness and sustainability.

Cybersecurity technologies: Event-driven systems suited for always-on, power-constrained threat detection. NC's feature of enabling local, efficient data processing, can reduce the need to transfer privacy-sensitive data.

Semiconductor technologies: Enables early fault prediction in semicon equipment and thermal efficiency in clean rooms through neuromorphic edge processing

Ministery of Economical Affairs and Climate (2024). National Technology Strategy.

NC has the potential to enhance, facilitate and optimize growth markets

- Dutch government is working on a **growth market strategy** (‘Groeimarktenstrategie’). A research report commissioned by Dutch government sees 12 growth markets where Dutch companies have a strong international position, where the market position is supported by knowledge positions and where global and national growth is to be expected.
- According to this **Growth Markets** for the Netherlands report there are 12 growth markets in the Netherlands with the most potential to enhance the earning capacity of the Dutch economy.
- Of these 12, neuromorphic computing has the potential **to contribute** to innovative and high-quality materials in the process industry, semicon, smart farming, medtech and climate adaptation.
- Although defense is not listed as a growth market in this specific report, the Dutch government has stated its intention to develop this sector further as part of its broader strategic autonomy and security agenda. Neuromorphic computing could **contribute to defense** by for example enabling safe edge computing for cybersecurity, real-time decision-making in autonomous defense systems, secure space operations, and information-driven land operations aligned with national high-tech priorities.

Innovative and high quality materials in the process industry: Neuromorphic signal processors classify sensor patterns for early-stage defect detection in material synthesis and coating processes

Semicon: Spiking neural networks perform edge-based fault prediction in semiconductor manufacturing equipment using high-frequency sensor input.

Smart Farming: Event-based cameras and neuromorphic controllers detect plant stress, growth anomalies, and pest activity under varying lighting conditions.

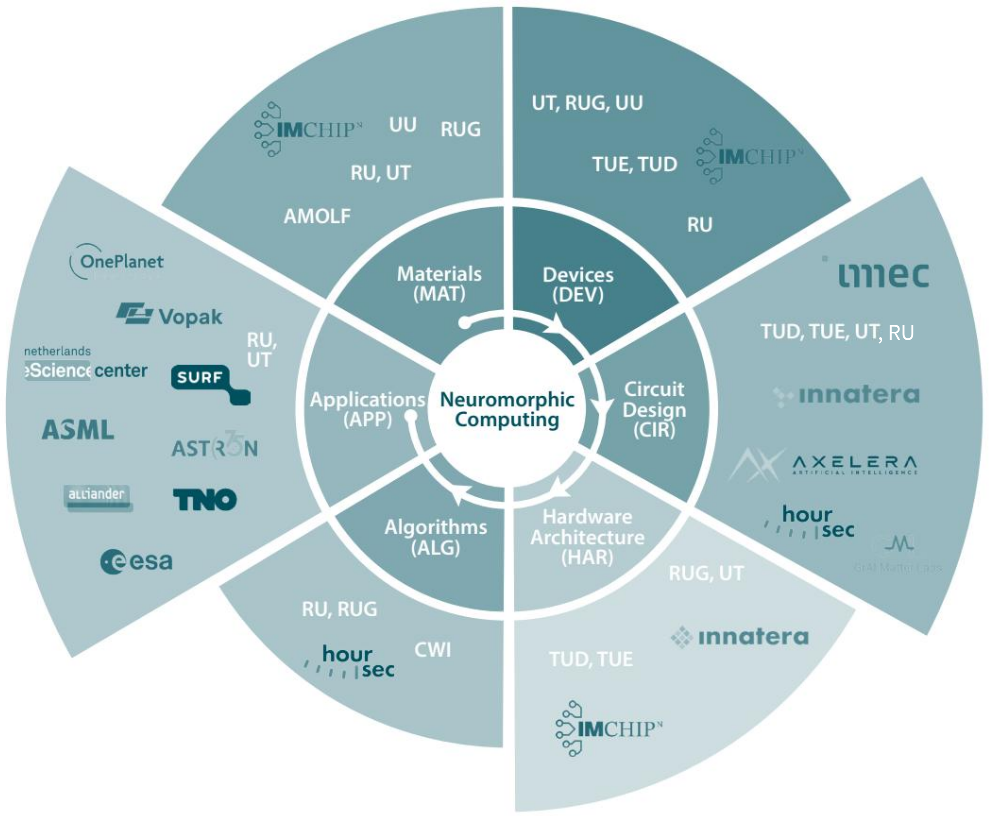
Medtech: Neuromorphic processors enable low-power, always-on biosignal interpretation in implantable or wearable medical diagnostic devices.

Climate adaptation: Neuromorphic environmental sensors analyze sparse temporal patterns in microclimate data for localized flood, drought, or heat stress forecasting.

Dialogic & SEO (2023). Growth Markets for the Netherlands.

Almost the entire neuromorphic value chain is represented in the Netherlands.

- Neuromorphic Computing is a paradigm on how computers can work more and more in the future if they function more like the human brain functions. The Neuromorphic paradigm includes **changes on all elements of the stack**: from materials through algorithms to applications. If all these elements change, the promise is that computers can be faster and just as effective in many applications, but with significantly less energy consumption.
- This is an attractive promise for data centers, which are costing more and more energy, but also for very small computers in places where grid power or battery power is not possible and where an efficient minicomputer could function on energy from ambient heat or movement, such as sensors in the human body.
- **The key areas of the neuromorphic stack are well-represented** by multiple organisations, including academia, companies, startups and public organisations. Currently, the only dependency lies in chip manufacturing, for example on companies like Taiwan Semiconductor Manufacturing Company (TSMC).
- There are **many researchers** in the Netherlands active in parts of NC, but Dutch researchers are active in all parts of the stack. It is also very attractive for researchers personally to be working on the computer of the future that thinks more efficiently and uses much less energy.
- The neuromorphic community has been **growing** in the Netherlands, creating the expertise and the momentum to advance the field.



Core team neuromorphic computing, powered by Topsector ICT (2024). Neuromorphic Computing in the Netherlands White Paper.

2. Impact potential | Use cases

Many potential applications, but further research for proof of use cases necessary

- Use cases and applications that need to fulfil a brain like function, such as imaging, audio, smell, radar or LiDAR and that would benefit from unique advantages that neuromorphic computing provides, have potential for commercial applications. These domains often involve dynamic, sparse, and asynchronous data, making them suitable for spiking neural networks and event-driven architectures.
- A concrete example of a solution that has already reached the market is the event-based camera, which captures visual information only when changes occur, rather than at fixed frame rates.
- Companies are interested in these opportunities, but hesitant, as more (applied) research is needed **to proof that potential use cases are more effective** and/or more efficient than the systems that are in place. An important element is **derisking** the use of neuromorphic computing as well.
- End-users need to be involved in the development process to achieve valorisation and commercial application. More research and development in public-private partnerships is needed to test which use cases have the most potential in the real world.

Aspects of neuromorphic computing

Functions

- Imaging
- Audio
- Smell
- Radar
- LiDAR

Unique advantages

- Energy-efficient
- Real-time data processing
- Massively parallel
- Low latency
- Event-driven
- Analog
- Anomaly detection

Based on interviews with experts and key stakeholders in the neuromorphic field.

Many potential applications, but further research for proof of use cases necessary

- Based on expert insights and current technological trajectories several potential use cases arise. **In the short term, applications are emerging at the edge**, enabled by accelerators operating at milliwatt levels. These include biomedical sensors, fitness trackers, event-based security systems, and automotive interfaces such as driver monitoring and decision support.

- **Progress depends on integration with conventional architectures to support more complex workloads.** This includes hybrid neuromorphic-digital chips, improved tooling for spiking neural networks, in-memory computing, and algorithm-hardware co-design. Promising sectors include agriculture, semiconductor manufacturing, industrial vision systems, and computer graphics. Signal processing in telecom and anomaly detection in finance also present opportunities.

- **Long-term impact requires novel materials and post-CMOS hardware.** These advances could enable breakthroughs in energy efficiency and computing performance, opening applications in healthcare, space, datacenters, and large AI models. For example, large language models (LLMs) are currently too power-intensive to run on edge devices, but neuromorphic architectures may one day make portable LLM deployment possible.

Market	Use case
Medical	• Noise-resilient sound processing in hearing aids • Continuous activity recognition in performance trackers
Automotive	• Event-driven processing and decision making in Driver Car Interfaces • Visual perception in low-light or adverse conditions in Direct Vision Systems
Telecom	• Signal processing in telecommunications
Industrial/ High Tech	• Fault prediction and control in semiconductor equipment • Self learning materials for industry optimization • Industrial machine vision
Financial	• Risk Control Mapping • Payment Volume Prediction • Fraud detection through anomalies
Security	• Detection of intrusions and unauthorized movements in event-based cameras • Data storage in the edge enhancing privacy and security
AI and datacenters	• Energy efficient image classification and generation, speech recognition and edge-computation

Not exhaustive

Based on interviews with experts and key stakeholders in the neuromorphic field.

2. Impact Potential | Long term ambition, vision and goals

Moonshot: "To compute as efficient and functional as the human brain"

The potential of neuromorphic computing resonates with national ambitions, such as outlined in the National Technology Strategy. As the Netherlands positions itself at the forefront of key enabling technologies, **neuromorphic systems offer strategic value** across multiple domains, including AI and data, semiconductors, photonics, and quantum.

To connect emerging capabilities with national and European goals, there is **a need for a clear, coordinated ambition that defines direction and scale**. During the interviews, several ambitions were voiced.

Development of intelligent materials and self-improving systems

- Develop materials that can make themselves smarter and build computational frameworks that can continuously refine themselves. This involves creating substrates that can perform intelligent tasks and integrating AI and computer science principles into the materials themselves.

Integration with existing technologies at system level

- Combine neuromorphic architectures with AI and data, quantum, photonics, and advanced semiconductors into a unified ecosystem around future proof computing. Creating neuromorphic systems that are highly energy-efficient and do not produce much heat and can therefore operate at room temperature is seen as crucial for applications where heat generation and power consumption are issues, such as in specific machines, datacentres and semiconductor applications.

Ecosystem development to enhance competitive advantage

- Build a competitive advantage for European actors by showcasing the real-world value of neuromorphic computing.

Prototyping and benchmarking infrastructure across the stack

- Develop facilities to test and demonstrate neuromorphic capabilities from hardware to applications.

Overcoming existing barriers and risks

- Addressing the challenges and obstacles in advancing neuromorphic computing research and applications is seen as a critical goal. This includes securing funding, developing the necessary infrastructure, and fostering collaboration between different stakeholders across science, industry and public institutions.

Based on interviews with experts and key stakeholders in the neuromorphic field.

In addition to social and technological impact, there is also economic and geopolitical relevance

1. **The Dutch knowledge position is strong**, and Dutch universities are investing in it (the arrival of the AI factory provides extra traction). It is worthwhile to make this knowledge position even more visible and relevant for Dutch companies and European consortia. It makes sense to set up a business council in which companies are explicitly challenged to translate their long-term roadmaps into concrete questions for the Dutch research community (and their spin-offs).

2. The movement towards NC will be inevitable for the next 30 years and will be unstoppable. The investments will be large worldwide. Most of the financial interests are in the (mostly **foreign owned) data centers.** Foreign owners like to place them also in the Netherlands (there are users there and there is access to sustainable energy from e.g. offshore wind). The Netherlands has an interest in data centers, but due to its limitations in grid access, it has to strive for more energy-efficient data centers. By co-investing in R&D in Neuromorphic Computing, foreign data centre investors can get access to Dutch research and gain more social and political support.

3. There are also Dutch data centers and for **geopolitical reasons**, the Dutch government attaches value to them. Due to their current size, they will not yet invest in neuromorphic technology that will only be economically more efficient in 10-30 years, but they can be substantive partners.

4. NC will also have consequences for the **semicon industry**. The Dutch semiconductor chain is strong with chip producers such as NXP and chip machine builders such as ASML; apparently NC is still too young for them to participate as a partner, but it is possible to explore how they can gradually become connected.

5. Work is being done on **a European alternative** to the American dominance in the IT field. The EU will continue to invest in this. It is possible to explore the extent to which NC from the Netherlands can play a role in this. At the moment, Dutch researchers are still mainly looking at American companies such as IBM and Google as a possible partner, but it is worthwhile to make an organized step to Europe. (In a Horizon Europe project on the combination of quantum and neurmorphic, Single Quantum B.V. is now working together with Dutch universities).

6. By the presence of almost the entire value chain of neuromorphic computing plus its feature of enabling local, efficient data processing, can reduce the need to transfer privacy-sensitive data and strengthen **digital sovereignty** in the Netherlands. This keeps the door open for a possible neuromorphic production facility in the Netherlands.

7. Researchers can also get guidance by taking a number of specific **use cases** further through prototyping and benchmarking. In this too, the Dutch government can articulate its own use cases and put them on the agenda of the Neuromophic community and thus have a legitimacy for research funding.

Based on interviews with experts and key stakeholders in the neuromorphic field.

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Current state of the NC ecosystem

How technology characteristics influence R&D-possibilities

- Neuromorphic Computing includes changes in all elements of the stack, but these changes are not necessarily all necessary for improvements in one element (unlike, for example, quantum computing, where new algorithms can only work on completely different hardware). New algorithms can also run on conventional chips and vice versa.
- The fact that the components of the stack can also be improved separately from each other means that the field of (potential) users is very broad and spread out. Unlike quantum or AI, there are no companies (in the world) that invest huge amounts of money for the development of the first working Neuromorphic computer. Many companies know that they are looking for Neuromorphic-functioning parts of the stack, they follow the parts that may be essential for them, but do not yet invest on a large scale.
- In the coming decades, the commercially largest application will be in servers and data centers that then require much less energy. All major players in this business are located outside the Netherlands (in terms of headquarters and decision centers), although their data centers are often located here. However, since neuromorphic computing is an emerging technology, it offers an opportunity to build new positions in the value chain, less dependent on existing Big Tech structures.
- The fact that the head offices are located elsewhere does not in itself pose an obstacle if the scientific achievements in the Netherlands are exceptional and if the nature of the technology requires large-scale R&D investments. In the quantum domain, for example, Microsoft and Intel invested tens of millions in research at QuTech in Delft, despite the low technology readiness level and long time to market. In neuromorphic computing, many startups are already entering the market and actively advancing the technology. Large companies remain hesitant in investing huge amounts in R&D. They are investing in research, although not yet at the scale seen in some other domains.
- There is a strong and diverse academic community with several key actors (including CogniGron at the University of Groningen, MESA+/BRAINS at University of Twente, Radboud Neuromorphic Computing Initiative in Nijmegen, Eindhoven Hendrik Casimir Institute, Faculty of EEMCS at TU Delft, CWI, and AMOLF).
- The fact that the components of the stack can also be improved separately also means that many researchers in this domain have one foot in the Neuromorphic community, but are also part of other IT communities and local institutes. The researchers who are active with NC are now working at at least six universities in the Netherlands (and at TNO). The volume of research is also large and spread over the Netherlands due to accidental circumstances. A large private donation made the growth of Cognigron (from 2018) possible, and the RUG can now make a new leap in scale in this field thanks to the *Nij Begun* resources.

Quantum and AI showed that public funding is important to progress ecosystem

- Between 2018 and 2023, Dutch scientists published 205 publications on neuromorphic technologies. At 1.7% of global output, the Netherlands has a relatively large share of publications. This places the Netherlands in ninth place among these countries.

- Researchers are spread across **multiple universities**, and there are several startups involved in the community, and there are now multiple places where they meet and where there is some alignment (Mision10X, Neuromorphic Now, the white paper core group). The white paper and the Neuromorphic Now days show that NC is an important **connecting theme and appealing paradigm.**

- The White paper describes the need for NC and promising applications. The **next step** is a document in which the Dutch researchers have described how their research relates to each other now and how it will build on each other in the future and how it will jointly and successively enable certain applications in NC.
  It is reasonable that different local research groups are looking for positions in a new theme such as NC, the next step is that there will be one central organization that can fulfill a role on behalf of all.

- Actually, there is some coordination at place with the application for a **KIC-LTP grant**, where a national consortium and a research program are now being worked on headed by RUG (Cognigron). For such a grant mutual strengths and division of roles between research groups have to be put on paper and companies are asked to participate.This application also has to include a narrative in the form of an Impact Pathway: which societal solutions will be identified and how will research contribute to them (this will be in line with the impact potential in chapter 2 in this document).

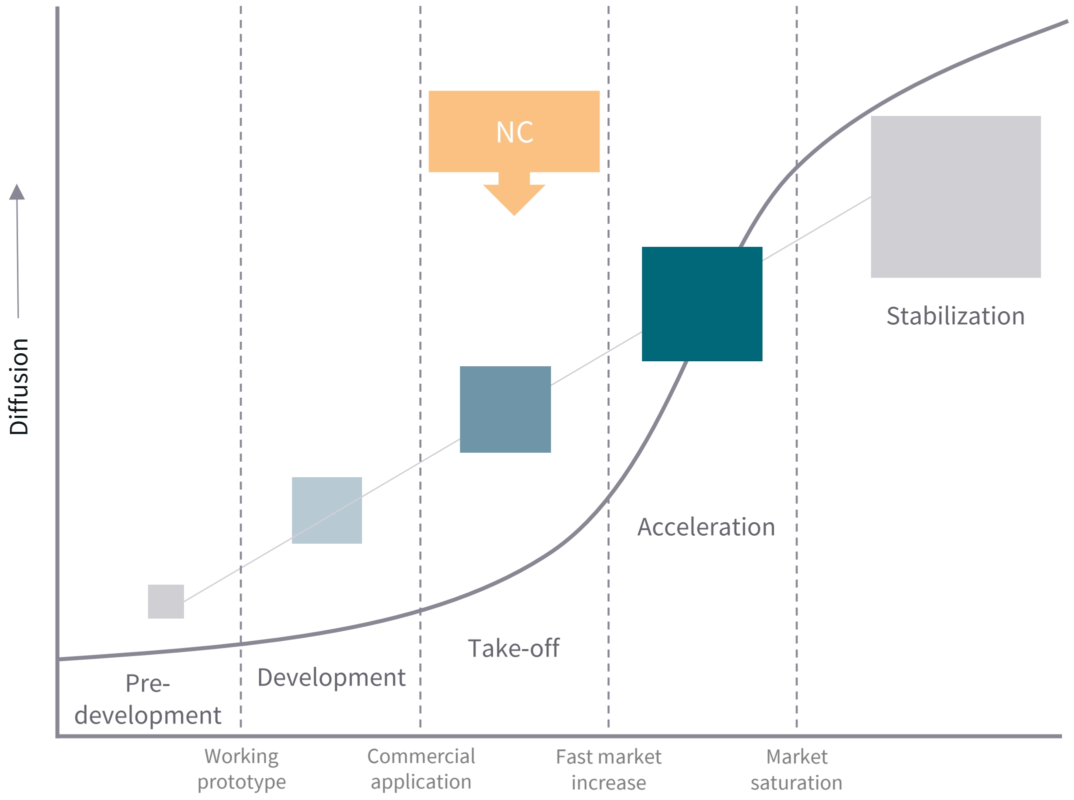
- For a coordinating body and board we can look at the **earlier experiences** at quantum and AI of QDNL or AIC4NL; these organizations have both benefited from the need of the Ministry of Economic Affairs for one central consultation point and benefited from an NGF application, these applications have yielded a lot for both communities, but such an application also forces a mutual division of roles and coordination. AI4NL is the successor of the Netherlands AI Coalition (NLAIC). This started in 2018 with a subsidy from the Ministry of Economic Affairs of 0.9 mE to set up a PPP in this area.

- Quantum computing and AI were greatly helped in their organization by the importance that the **Ministry of Economic Affairs** attached to them (and the financial resources that the Ministry of Economic Affairs had available for organizational formation at the time). Currently, PPPs and the NGF are not accessible, though a new cabinet may revise this. The main instrument now is the top sectors developing an action agenda for NTS technologies, alongside the ambitions outlined in the Ministry's 3% R&D action plan, which emphasizes strengthening strategic technologies and valorization infrastructure.

Ministry of Economic Affairs (2025). Investing in a Resilient and Future-Proof Economy: The 3% R&D Action Plan.

Different technology layers and stakeholders are at different stages of readiness

- The different key areas of neuromorphic computing have **different technology readiness levels (TRLs)** and therefore different needs. Neuromorphic hardware is at a lower TRL level than the software.
- Different stakeholders also appear to be at different stages of readiness. While researchers lead in lab-scale innovation, **user companies and governments remain cautious** due to missing demonstrators, use cases and real-world proof, highlighting the need for collaboration across the stack.
- The Netherlands has strong academic expertise, a lot of startup activity and early involvement in national and EU collaborations, but **is lagging behind in public and private investment and valorization infrastructure**.
- Different initiatives, such as **NL-ECO and Mission 10-X and research center CogniGron** are already (partially) focused on advancing neuromorphic computing. In 2024, Cognigron presented the TEXEL chip, a mixed-signal neuromorphic architecture designed to bridge the gap between CMOS-based computing and emerging memory technologies, offering a practical platform to integrate and test novel devices and on-chip learning in real-world conditions.



Hekkert et al. (2007). Functions of innovation systems: A new approach for analysing technological change. Technological Forecasting and Social Change. 74-4, pp 413-432. | Based on interviews with experts and key stakeholders in the neuromorphic field.

Necessary action to advance the NC field

Ecosystem needs are directly linked to anticipated technological developments through time

- The coming years the neuromorphic computing field will keep evolving. A very high-level overview of expected and necessary technological developments on the short, medium and long term is given on the right. These phases were distinguished based upon expert interviews, although it is hard to define the exact timeline as the neuromorphic field is very dynamic.
- To develop software-hardware system architectures for neuromorphic computing, **researchers from multiple disciplines (e.g., physics, material science, software engineering, computer science) need to work together.**
- The Netherlands need to make **early-state investments** to take technologies at higher TRL levels from research to prototype. An ecosystem is needed where capabilities can be showcased, to get more industry stakeholders on board.
- At the same time, **fundamental research needs to be stimulated** at lower TRL levels, so the entire value chain can develop on the long term.
- Stakeholders have emphasized the need for a **shared technological vision** to guide the development of neuromorphic computing. Beyond setting priorities, such a vision can help the community connect different strands of research, and chart a path from early-stage innovation to practical use. It would also support alignment with broader national and European strategies, strengthen the case for funding.

Short term: Applications based on existing hardware. These are already available and can now be linked with neuromorphic architectures. It is easier to begin by building on what already exists in the current industry. This requires a more flexible setup. No entirely new device concepts are needed at this stage. The goal is to build new systems using existing building blocks. Companies like Innatera, Hoursec, Snap and AccelerAI are working in this space. These systems are compatible with digital chips but are gradually shifting toward neuromorphic computing. This might include spiking neural networks (SNNs), FPGAs, and in-memory computing. Parts of the system can be analog, as long as fabrication is made accessible. Mixing analog and digital is possible, provided analog computation delivers significant benefits.

↓

Medium term: A further shift toward new materials and device concepts. For example, memristor-based analog in-memory computing (RRAM).

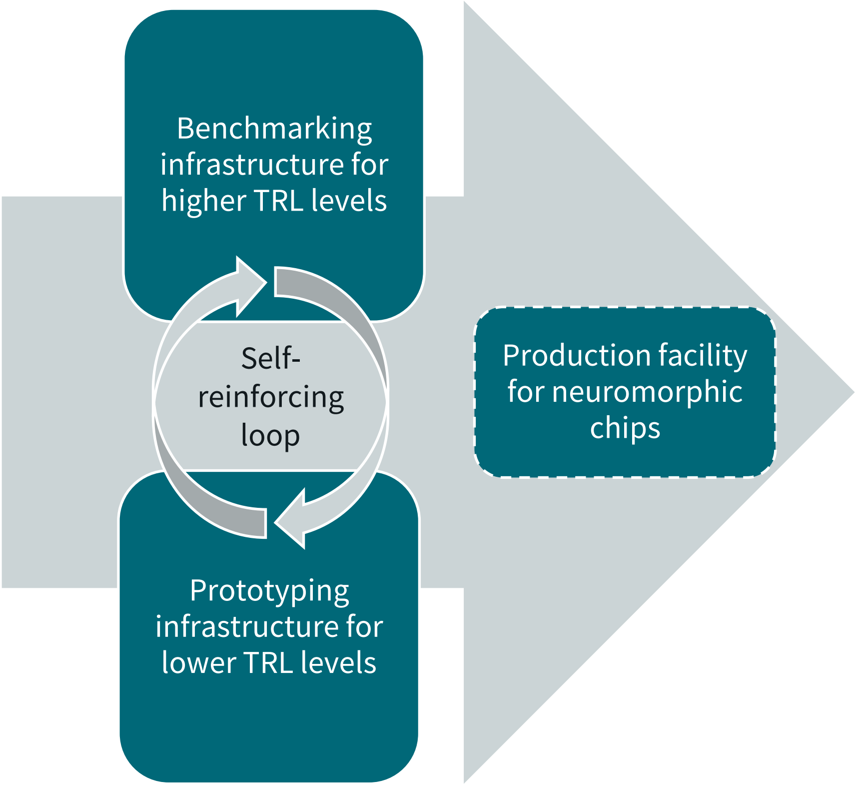
↓

Long term: A deeper step into the stack. New materials will emerge that enable redesigned devices and systems. The vision includes adaptive, self-learning systems, where learning processes are visible at the material level itself.

Based on interviews with experts and key stakeholders in the neuromorphic field.

Benchmarking and prototyping infrastructure is needed to progress the neuromorphic computing field

- Dutch capabilities in NC have matured to the point where targeted infrastructure is essential. Input from researchers, startups, companies, SURF, and TNO highlights the need for an accessible system that supports the full development chain. The first short-term priority is a **benchmarking infrastructure** for existing platforms (e.g., Loihi, SpiNNaker, AxeleraAI, Innatera, TEXEL), enabling standardized testing of neuromorphic capabilities. FPGA-based systems could serve as transitional tools, especially for edge-AI use cases.
- A second short-term priority is a **prototyping infrastructure** for low-TRL development of materials, devices, and neuromorphic architectures. Positioned between academic labs and full-scale facilities, it should support low-barrier experimentation, which will help identify scalable innovations and accelerate transitions from research to demonstrators.
- Benchmarking and prototyping together establish a **self-reinforcing development loop**. The interaction between these components supports software–hardware co-design by aligning algorithmic needs with architectural and device development. This dynamic fosters attracts talent, reduces industrial adoption risks, and helps attract investments.
- The third long-term step could be to establish a **neuromorphic chip production facility** in the Netherlands. While small-scale, this would remove one of the only existing dependencies in the national value chain, supporting sovereignty and commercialization of Dutch-developed technology.
- These steps should be accompanied by education (e.g., master tracks, joint programs), knowledge sharing, and ecosystem events.



Based on interviews with experts and key stakeholders in the neuromorphic field.

Public and private investment is essential to advance neuromorphic computing

- To realize the required infrastructure, total financing of **approximately €30 million is needed over the next five years**: €20 million for prototyping and €10 million for benchmarking. This is relatively cheap compared to the €200 million that was invested by the TU/e for a semiconductor lab and cleanroom. With funding secured for just the first two years, early activities can already begin.
- Part of the required budget may come from existing instruments (an overview is given in appendix 3) such as the NWO TTW Perspective call (with a maximum of €5 million and a university as lead applicant). **Additional funding should be co-financed by companies contributing time or capital**, supported by use cases.
- The next step would be to gather broad support from both industry and public stakeholders and to progressively present a more detailed plan to the Ministry of Economic Affairs. This allows the neuromorphic community, via the ICT Top Sector, to **align with evolving EZ policy on experimental infrastructure**.
- Some proposed actions can already be initiated during this cabinet period, provided they fit within current policy, the demissionary status, and existing budget frameworks. Other measures that require additional public funding or lie outside current policy will need new decisions, in which case funding is unlikely before 2027. While it remains unclear which actions fall into which category, early alliance-building and a broadly supported technological roadmap are important to secure future investment tailored to NC.

In its recent policy letter *Investing in a Resilient and Future-Proof Economy: The 3% R&D Action Plan* (July 11, 2025), the Ministry of Economic Affairs (EZ) outlined several new instruments to strengthen the Dutch innovation landscape. A key priority is to stimulate R&D growth primarily within companies, particularly those operating in strategically important value chains.

For neuromorphic computing, the letter presents a promising direction: increasing support for experimental facilities aimed at R&D-intensive start-ups and scale-ups. EZ will explore how access to existing prototyping and experimentation infrastructure can be made more affordable, for example through structural public co-funding of facility usage costs where this is of strategic relevance to the Dutch Technology Strategy (NTS).

The content of the letter, emphasizing AI, European sovereignty, valorization, and experimental capacity, offers opportunities for neuromorphic technologies. However, the ministry aims to back initiatives led by industry. To engage effectively, the NC field will need a clear proposition supported by leading Dutch companies, alongside academic partners and a joint governance structure. A strong industry representative, or figurehead, could help make this case more compelling at the policy level.

Ministry of Economic Affairs (2025). Investing in a Resilient and Future-Proof Economy: The 3% R&D Action Plan.

3. What needs to happen?

Outcome-oriented governance structure with strong scientific expertise and industrial base is needed

To develop neuromorphic computing in the Netherlands, it is essential to bring together **people who connect disciplines**, those who can bridge between algorithms, mathematics, engineering, and physics. These fields all need to be represented and actively involved.

The white paper describes the need for NC and promising applications. The next step is a document in which the Dutch researchers have described how their research relates to each other now and how it will build on each other in the future and how it will jointly and successively enable certain applications in NC.

A coordinating structure is needed, with a decentralized setup. It is reasonable that different local research groups are looking for positions in a new theme such as NC, the next step is that there will be one central organization that can fulfill a role on behalf of all. This organization should be explicitly responsible for **securing funding** that is needed to deliver specific outcomes, not just for convening meetings or facilitating networking. The structure should be both industry, science and society oriented. It should have close ties with the neuromorphic community in the Netherlands, and internationally.

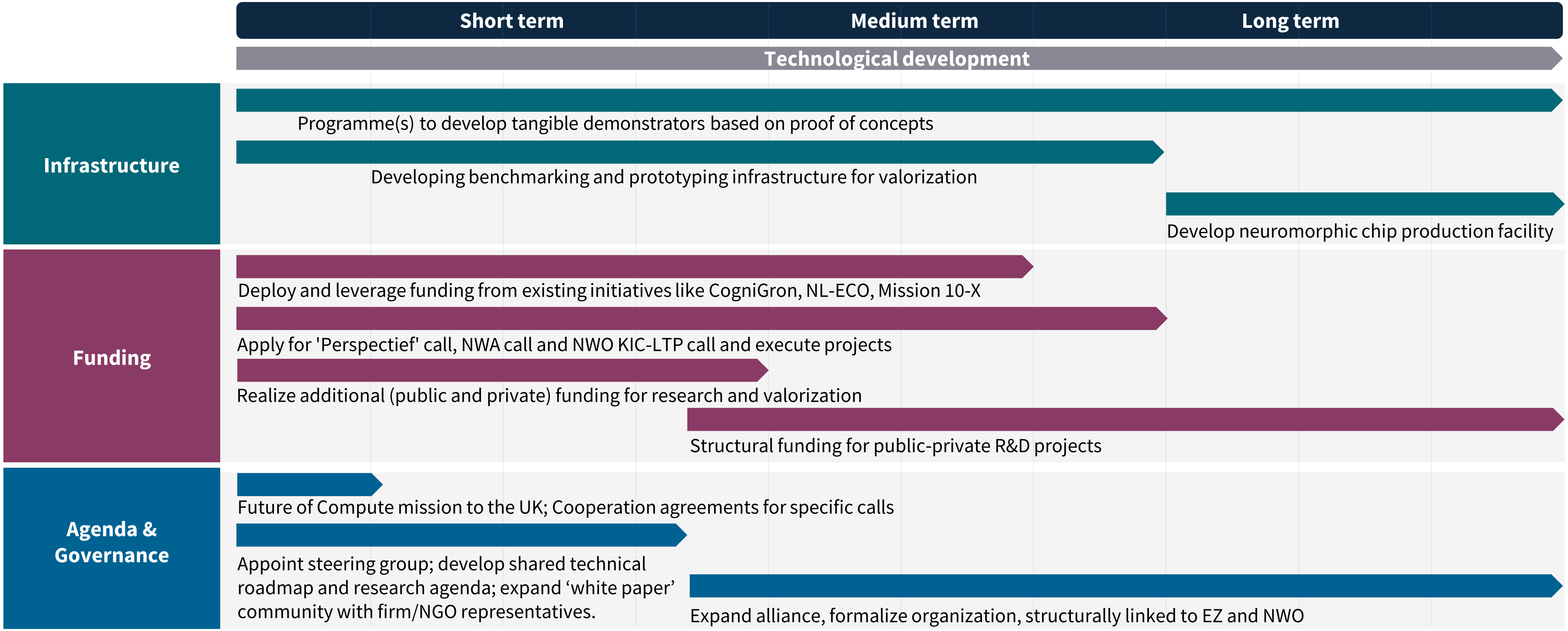
Promoting neuromorphic computing at the **European level** should be part of the mission, through proactive lobbying and visibility efforts. A key mechanism here is the recruitment of people who operate at the intersection of academia and industry. They can help translate knowledge, accelerate cooperation, and guide companies toward relevant developments. The Dutch alliances can also participate on behalf of its members in European platform an associations as STANCE (Strategic Alliance for Neuromorphic Computing and Engineering).

To increase adoption, a service to support (new) interested companies can be developed to better understand the technology. **Educational initiatives** should be made available, and a clearly identified point of contact should be appointed, someone who can answer industry questions and act as a first link into the ecosystem.

One of the current challenges is the lack of investment from both public and private players. Governance should focus on enabling early demonstrators that show the concrete value of neuromorphic computing. **Building credible use cases can increase confidence and attract broader investments** across the ecosystem.

Based on interviews with experts and key stakeholders in the neuromorphic field.

Neuromorphic ecosystem can progress with efforts on infrastructure, funding and governance



Based on interviews with experts and key stakeholders in the neuromorphic field.

Birch
Long version

Steps to take on the short term

4. Suggested sequence of steps to take on the short term

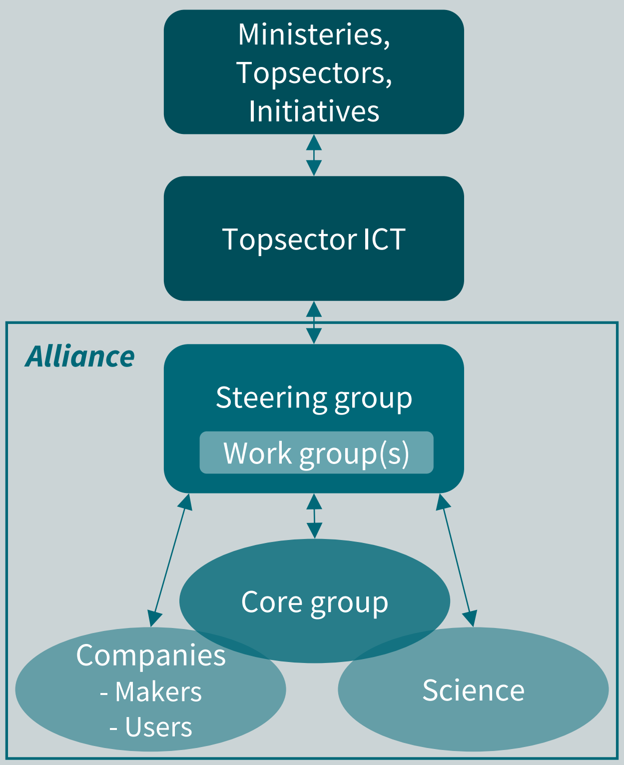
- Following our analysis of the technology and the current organization of the ecosystem, and based on our expertise and experience with models elsewhere, we see the following short-term steps.
- Steps 1–4 require at least 0.5 FTE for three-quarters of a year, in addition to the time contributed by all participants.
- An important upcoming opportunity to position neuromorphic computing within the national and international strategic agenda is the Future of Compute mission to the UK, organized jointly with the Dutch embassy and scheduled for early November. This mission offers a timely moment to present a strong narrative around Dutch ambitions and capabilities, and to explore opportunities for research collaboration and business partnerships in the United Kingdom (UK).

1. Let the Topsector ICT convene a steering group

A steering group will be formed in which industry and scientists jointly determine the direction for the steps the neuromorphic community needs to take. At this moment, the Topsector ICT is the most logical convener of this steering group. The group will consist of an equal number of members from industry and academia. If all universities active in NC (TUD, UT, RU, RUG, and possibly TU/e) participate, five non-university members would be appropriate, examples include TNO, a startup, a large company active in NC, and a company that is (potentially) a user of NC, for example ING, Op-Net, Toyota or Alliander.

The researchers and SURF already have an organized base in the form of the current core group involved in the white paper. This provides a contact point and a sounding board. For companies, such an organized base does not yet exist. The Topsector ICT can start with companies that are representative of neuromorphic activity. The ambition is to include companies in the steering group that have strong connections with business networks and associations relevant to NC (e.g., NL-Digital, Dutch Data Center Association, AIC4NL). The Topsector ICT can initiate these contacts. It will also invite the Ministry of Economic Affairs and Climate Policy (EZ) to participate in the steering group.

Governance suggestion for steps 1-4



Note: Step 1 should be seen as sequential to step 2,3,4 and 5, not parallel. A basic governance structure must be in place before other steps (technical roadmap development, stakeholder alignment, and infrastructure planning) can proceed effectively.

Team analysis based on research and correspondence with neuromorphic computing stakeholders.

4. Suggested sequence of steps to take on the short term

2. Develop a strategic technological roadmap

The steering group will draft the first technological roadmap, which could include:
a. What is the shared tech vision for neuromorphic computing over the next 10–30 years? What technological advances are needed to achieve this?
c. How can organizations with strengths in different stack layers collaborate to create complementary technologies and strengthen the value chain? Could this take the form of a flagship project?
d. How should hardware/software co-designs, prototype test beds, benchmarking infra, integration and (open-sourced) tooling be structured, taking standardizability into account?
e. Which stack technologies offer export potential?
f. Which non-developer companies have a strategic interest in neuromorphic computing, and in which application areas can it help overcome capacity limits or improve competitiveness?

It is logical that not the entire steering group tackles this work but rather a working group from within it.

3. Build broad support for the strategic technological roadmap

While the roadmap is being drafted, the Topsector ICT and the steering group will organize a dialogue with relevant researchers, knowledge institutions, initiatives, network organizations and companies outside the group. Draft versions of the roadmap will be made available on the Topsector ICT's website, and all relevant researchers and companies will be notified (this marks the beginning of the alliance). The ambition is to ensure that not only individual researchers and companies support the roadmap, but also academic departments, research institutes, and business associations. The goal is for at least 20 companies and their associations to support the roadmap. All individuals, companies, and organizations that want to remain involved can join this alliance.

4. Use roadmap to secure funding

This technological roadmap will serve as a narrative for funding proposals in research calls. These calls often require an "impact pathway" that explains how research will translate into applications with societal and economic impact. Because companies and their organizations support this roadmap, there is a pool of businesses available that can be approached as partners (and co-funders) in consortia submitting proposals to NWO or the EU. The Topsector ICT will bring this roadmap to the attention of the Ministry of Economic Affairs (EZ), aligned with the AI, Data, and Cyber action agendas being developed in connection with the National Technology Strategy (NTS). The NTS elaboration currently underway will impact both existing and new EZ instruments.

Note: Steps 2, 3, and 4 should be seen as running in parallel to step 5, rather than strictly sequential. The development of prototyping and benchmarking infrastructure is a short-term priority that can and should start independently of a fully developed technological roadmap. In fact, early insights from these facilities will inform and shape that roadmap.

Team analysis based on research and correspondence with neuromorphic computing stakeholders.

4. Suggested sequence of steps to take on the short term

- This step will again require about three months to develop a plan concrete enough to attract co-financing from industry and NWO and be eligible for NWO submission.
- In the first year, a steering group will operate, as there is not yet an entity with legal standing. Once steps 1–5 have been completed and the steering group has demonstrated commitment to leadership and collaboration, the next step can be taken. A legal entity, such as a foundation with its own board, can be created to demonstrate independence from any single university.

5. Develop benchmarking and prototyping facilities

To improve knowledge, support valorization, and provide guidance to researchers, a prototyping and benchmarking facility should be created for priority application areas. This aligns with the "experimental space" described in EZ's recent letter. Such a facility will enable sequential testing of components within the neuromorphic stack. Proposals for use will come from a researchers and companies. Two types of combinations are possible:

a. Dutch researchers with Dutch companies.
b. Dutch researchers with Dutch and foreign companies that demonstrate strategic interest in Dutch knowledge through this collaboration.

For prototyping and benchmarking, a standardized framework for hardware-software co-design is crucial, including an interface between systems. This framework does not currently exist. The best ways to do this have to be determined during the development of the tech roadmap. One potential setup is as follows: SURF has the expertise to develop such frameworks and would be well-suited to coordinate this activity. Organizations such as Imec can host a small neuromorphic accelerator. This would allow algorithm developers access to the hardware and benefit software development. Imec can contribute knowledge and IP licenses, for example generic IP licenses that can be tailored to specific applications. However, Imec cannot fund this independently.

Orgware needs

- ❑ End-users that can bring in use cases
- ❑ Research with a recognized and recognizable division of labour
- ❑ Criteria for prioritising use cases
- ❑ Criteria for assessing and benchmarking application-tests
- ❑ Models for cooperation between universities and competitors (IE, ROFR, etc.)

Hardware and software needs

- ❑ Computing capacity (neuromorphic, hybrid or conventional)
- ❑ Licences for startups and SME's
- ❑ Infrastructure (and staff) for building stacks and combining edges, software, layers and hardware
- ❑ Protocols for compatibility
- ❑ Location for testing and meeting

Note: Step 5 should be seen as running in parallel to steps 2,3 and 4, rather than strictly sequential. The development of prototyping and benchmarking infrastructure is a short-term priority that can and should start independently of a fully developed technological roadmap. In fact, early insights from these facilities will inform and shape that roadmap.

Team analysis based on research and correspondence with neuromorphic computing stakeholders.

Appendices

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1. Respondents interviews

List of experts from industry, research, and public organizations who gave their insights

Name	Organization
Wilfred van der Wiel	UT
Federico Corradi	TUE
Marcel van Gerven	RU (Donders Institute)
Georgi Gaydadjiev	TUD
Amir Zjajo	Innatera
Orlando Moreira	Snap
Alexandra Pinto	Hoursec
Bert Offrein	IBM
Mariana Gómez de la Villa & Cees van Wijk	ING
Erik Wijnen, Jasper Munnichs, Simon de Jong & Joris Jansen	Ministery of Economic Affairs
Taras Matselyukh	Op-Net
Paul Blank	NWO
Sagar Dolas	SURF
Said Hamdioui	TUD
Dirk Pleiter, Beatrix Noheda & Jesse Siegers	RUG and Cognigron
Kanishkan Vadivel	IMEC
Alexander Khajetoorians	RU
Johan Mentink	RU
Hans Hilgenkamp	UT and NL-ECO

2. Funding: three streams and funding routes

Three streams fuel each other with ideas, partners and feedback

Fundamental research	Public-private (applied) R&D	Testing, Valorisation and benchmarking
• NWO National Science Agenda – "Onderzoek op Routes door Consortia 2025" (untill February 3th 2026, max. 6.75M euros per application) • NWO Open Competition ENW - M (untill July 31th 2025, max. 0.8M euros per project) • NWO KIC LTP	• Chips Joint Undertaking Calls: • Research and innovation on Electronic Components and Systems: high-performance computing • Horizon Europe Calls Pillar II, Cluster 4, Digital, Industry and Space: World leading data and computing technologies • Open Technologieprogramma (ongoing, 950 thousand euros per programme) • NWO TTW Perspectief (ongoing, 2-5M per project) • Link to existing NGF programmes like PhotonDelta • Action-agendas topsector ICT and High-Tech	• NWO: Valorisation-instrument Demonstrator (TRL-4) • NWO Take-Off fase 1 en 2 for academic Spin-offs • RVO MIT • Dedicated calls for Defense (Fast-track) and healthcare applications

TRL →

Colofon

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