Fraunhofer ISI

obserVe

Project Name	Observing Emergence OBSERVE
Project No.	665136
Project Type	Coordination and Support Action
Project Duration	1.6.2015-30.5.2017 (24 Months)
Project Coordinator	Philine Warnke, Fraunhofer ISI
Funded under	Future and Emerging Technologies FET OPEN CSA
Workpackage	WP 1 Horizon Scanning
Deliverable	**1.1 FET Portfolio Report**
Planned Date	Month 8
Actual Submission	March 2016
Version	1.0
Author	Bernd Beckert

Contents

The FET Portfolio Report

1 Introduction, samples and methods used

The main task of the observe-project is to identify new and emerging technology areas. One important source for identifying new and emerging technology fields is the FET programme itself, respectively the current research projects funded by this specific programme.

The rationale behind this is that FET projects can be considered as indicators for new topics in research and technology. Both schemes within the FET programme, FET Open and FET Proactive, encourage researchers to turn in research proposals that explore new ideas, concepts, approaches and technologies in a collaborative and trans-disciplinary manner. There is a special emphasis on non-mainstream and high-risk research.

In this report, we will have a closer look at the spectrum of research topics explored by FET projects. The aim is to analyze a set of recent FET projects and to propose a bottom-up clustering of topics. The topical clusters will then be fed into the Horizon Scanning process of observe.

For both tasks, the portfolio-analysis and the bottom-up-clustering, we will use specific project samples and a different set of methods. The portfolio-analysis will examine a total of 132 FET Open and FET Proactive projects ending in 2015 and beyond. The method of the portfolio-analysis consists of a counting of budget data and enterprise participation in the consortium as well as a manual assessment of the interdisciplinarity level in each project. Also, we have determined the most frequent disciplines represented in the different clusters of projects. The portfolio-analysis will use the 12 topical clusters given by the European Commission (AI & Cognition, Complexity, Bio- & Neuro-ICT, etc.).

For the second part of this work package, the bottom-up clustering, we will use a different sample of FET projects, namely 67 recently finished or still ongoing FET Open projects. We decided not to consider FET Proactive projects for the clustering because these projects follow pre-given topics issued by the respective FET Proactive calls. We would expect to find clusters here which are very similar to the topics set in the calls. Thus, FET Open projects seemed to be better indicators for new topics as proposers are totally free in choosing their research topics.

The method for the bottom-up clustering consists of a predominantly manual clustering which is based on expert content analysis supported by keyword analysis as an additional source. As clues for the clustering we used the titles of the projects, the project abstracts which can be found in the Cordis database and the set of keywords given by the respective research teams. We decided not to use project publications because some of the projects have just started and do not provide a publication list in Cordis yet. The topical classification according to journal subject fields would in fact result in a clustering which is too broad for our purposes, as it only indicates disciplines and research sub-fields of the respective projects. Conversely, a single keyword-analysis which counts frequencies of keywords would yield too narrow results for our purposes.[1]

The foreseen synergies with the project FET_TRACES in which an impact assessment of finished FET projects is being carried out could not be realized in the planned way because of the different project samples which have no overlap. FET_TRACES only analyses finished projects whereas in observe we use the most current set of FET projects as indicators for new topics in science and technology development. However, synergies have been realized concerning the method of determining the level of interdisciplinarity. The respective conceptual findings in the FET_TRACES project could also be used in observe to determine the interdisciplinarity level accordingly. Also, a preliminary portfolio-analysis of FET_TRACES could be used to contrast the results from the observe-sample concerning the number of projects and their budgetary size within the pre-given topical clusters.

1 The keywords database which was provided by the European Commission was used as a complementing source for the bottom-up clustering. In a different exercise, we carried out a sophisticated, semi-automated keyword analysis using this source. This exercise was carried out in addition to what was announced in the observe-proposal. The results of the keyword analysis were also fed into the Horizon Scanning process of observe. The method and the results are documented in the Methodology Report (D 1.3).

2 Portfolio-analysis

For the portfolio-analysis we use the twelve topical clusters given by the FET Unit (see figure 1). All relevant 132 FET Open and FET Proactive projects which were finished in 2015 or which will end in 2016 to 2018 (see list in appendix A) were assigned to these clusters by the European Commission.

Figure 1: The twelve pre-given topical clusters

Source: FET Portfolio, http://ec.europa.eu/digital-agenda/en/fet-projects-portfolio

To give a short overview, what topics are being explored in the different clusters, we present the portfolio-descriptions by the FET unit as it can be found on the Websites of the programme at http://ec.europa.eu/digital-agenda/en/fet-projects-portfolio. Two of the topical clusters are not relevant in our context: "Information & Modeling", in which only 2 projects are subsumed and "Practices & Communities" which also comprises of only two projects, both being CSAs.

Figure 2: S&T topics in the relevant FET clusters as presented by the FET programme

Understanding by building is at the heart of research in Artificial Intelligence (AI) and cognitive systems.

This area explores synergies between cognitive science and the neurosciences, but also the social sciences and humanities to create technologies for intelligent systems. Creativity, context awareness, associative reasoning, learning, adaptation, evolution, emotion and social intelligence are some of the topics addressed.

For example, projects deal with:

- Trying to use real bacteria for computing (EVOPROG)
- Trying to use real bacteria for cell-to-cell communication (PLASWIRES)
- Designing computational architectures using the nervous system as a blueprint (SI ELEGANS)

The convergence of biology, nanotechnology, neuroscience and information technology is interfacing wet and dry technologies.

This convergence creates tools to better study one or the other, to create hybrids between them or to use inspiration from neuroscience and biology to create better systems (sensors for instance). Neuroprosthetics is an important area of application for this.

For example, projects deal with:

- Designing swarm-robotics using insights from cellular level morpho-genesis in plant roots (SWARM-ORGAN).
- Using plants as sensors for pollutants (PLEASED)
- Using real bacteria for parallel computing (ABACUS)
- Artificial eyes: Developing a silicon retina (SEEBETTER)
- Retina-inspired encoding for advanced vision tasks (RENVISION, VISUALISE)

When many simple systems start to interact, anything can happen.

In complex systems, even if the local interactions among the various components may be simple, the overall behaviour is difficult and sometimes impossible to predict, and novel properties may emerge. Understanding this kind of complexity is helping to understand many different phenomena, from financial crises, global epidemics, propagation of news, connectivity of the internet, animal behaviour, and even the growth and evolution of cities and companies. Mathematical and computer-based models and simulations, often utilizing various techniques from statistical physics are at the heart of this initiative.

For example, projects deal with:

- Exploiting evolutionary computation principles to build bio-hybrid adaptive systems (ASSISI_bf)

Computers are everywhere, but is computer science ready for it?

This is the challenge in this area where projects are pushing information theory, algorithmics, signal processing, communication protocols, cryptography and other core areas of computer science to a new level of ambition where the high expectations that others have from it can really be met.

For example, projects deal with:

- Speed of adaptation in population genetics and evolutionary computation (SAGE)

How will we progress to massively parallel systems, possibly using millions of cores?

How to overcome the strict separation between memory and processing functions? How to deal with the changing balance between computing power and data intensity? How will we build computers so complex that component failures are a way of life?

For example, projects deal with:

- Heterogeneous Ad-hoc Networks for Distributed, Cooperative, and Adaptive Multimedia Signal Processing (HandiCAMS)

Energy consumption is one of the biggest hurdles towards achieving green computing and networking.

A growing number of projects are tackling this problem head on.

For example, projects deal with:

- Operating ICT basic switches below the Landauer limit (LANDAUER)

The screen, the keyboard, the mouse: is that how we will interact with computers forever?

Of course not! In the future computers may speak and understand natural language, engage all our senses (touch, smell, ...), understand what we want ('Help me!') from the context, or adapt to our mood. Embedded in our living environment or' disguised' as robots, everyday objects, in our cloths or behind 3D interfaces, we will simply forget about them and enjoy the magic they create for us.

For example, projects deal with:

- Making a computers learn to recognise and produce a sound which is being described verbally and non-verbally by gestures (SKAT_VG)

Devices that exploit quantum phenomena such as superposition and entanglement of quantum states have the potential to enable radically new technologies.

Several promising directions are now well known, for instance quantum simulation, quantum communication, quantum metrology and sensing, and the quantum computing in a long term. FET projects in FP7 have kept on exploring these new mind-boggling possibilities and have produced some world class fundamental results, while also pushing other topics, like quantum key distribution, metrology and sensing, to the level of more practical use.

For example, projects deal with:

- Scalable Superconducting Processors for Entangled Quantum Information Technology (ScaleQIT)
- A Guided Matter-Wave Interferometer on a Atom-Chip (MatterWave)

This area is pushing science and engineering of robots beyond fiction.

Robots inspired by plants, octopus or insects. Swarms of robots with emergent behaviours, evolving and shape-changing robots? These are some of the topics explored in this area.

For example, projects deal with:

- Mimicking roots developments in a plant-like artefact (PLANTOID)

Computers are tireless in shuffling ones and zeros around.

Why ones and zeros? And why with currents, transistors and silicon chips as in any computer, laptop, mobile phone or tablet today? These projects show how to compute with, for instance, light, sound, molecules or bacteria. They show how to encode information in different ways, like analog or in electron spins. They question the meaning of computing, and push the limits of what is computable.

For example, projects deal with:

- Trying to use cellular processes as a basis for parallel computing (BIOMICS)
- Programming cellular networks and community behaviour with synthetic RNA-based devices (RIBONETS)
- Using mathematical methods to detect cancer in tissues in real-time (Helicoid)

In the portfolio-analysis we will display the number of projects funded within the topics, the budgetary strength of the cluster, the degree to which cross-disciplinary research characterizes the specific topic and show, from which disciplines/ research fields the most projects supported by the FET programme come from.

2.1 Relative importance of thematic clusters

Of the 132 FET Open and FET Proactive projects in our sample, the most projects were grouped into the "Unconventional Devices" topic (35 projects or 26% of all projects in the sample). Second and third places according to the number of projects are "Bio- & Neuro-ICT" (22 projects making a share of 17% of all projects) and "AI & Cognition" with 14 projects or 11 percent of all (see table "Number of projects in topical clusters").

Table: Number of projects in topical clusters

Topics in FET	No. of current projects	Percentage of current projects	Percentage of older projects
Unconventional devices	35	26	25
Bio- & Neuro-ICT	22	17	13
AI & Cognition	14	11	3
Quantum & Photonics	11	8	15
Complexity	11	8	8
Human-Computer-Interaction	11	8	9
Computer Science	9	7	13
Green Computing & Networking	8	6	4
Computing architectures	6	5	4
Robotics	3	2	2
Information & Modeling	2	2	3
Total	132	100	100

„Current projects" refers to FET projects which ended in 2015 and which will end 2016+, without CSAs, n=132. „Older projects" refers to FET projects which ended between 2011-2014, n=130, without CSAs, missing cluster „Practices & Communication" has only 2 projects which are both CSAs.

Comparing the recent sample of projects with a sample of FET Open and FET Proactive projects which were finished between 2011 and 2014, we can see which topics have become more important over time. With utmost caution it can be said the following topics have a stronger dynamic than others:

- "AI & Cognition": Only 3% of all projects in the earlier sample were grouped in this topic whereas in the recent sample it makes for 11 % of all projects.
- "Bio-& Neuro-ICT": Up from 13% of the whole sample in the earlier time slot to 17 % in the recent sample
- "Green Computing & Networking": Up from 4% to 6%.
- "Computing architectures": with only a slight increase from 4% to 5%.

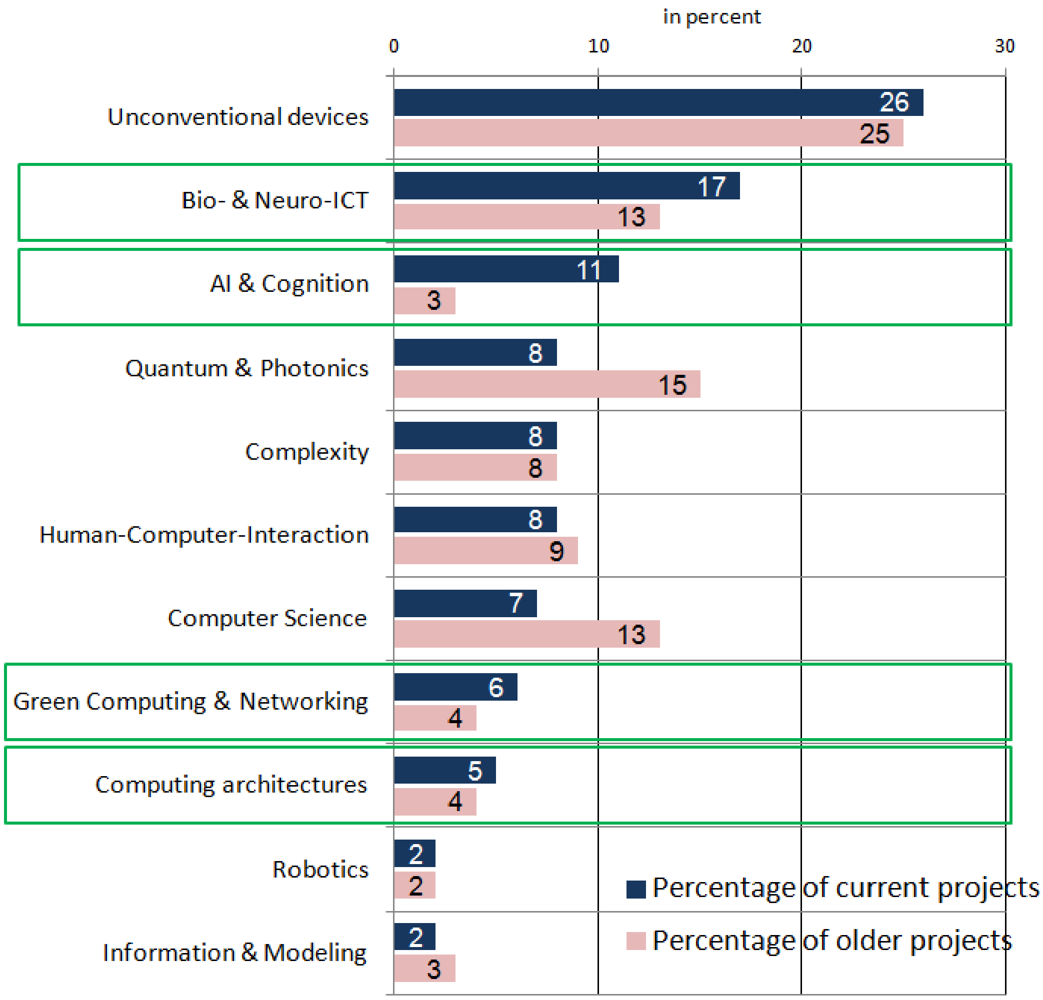
The most dynamic fields are marked with a green frame in the figure “Number of projects in topical clusters.

In turn, topical clusters which are currently weaker in terms of number of projects compared to the earlier time slot are:

- “Quantum & Photonics”: Down to 8% from 15% in the earlier time slot.
- “Computer Science”: Down to 7% from 13% in the earlier time slot.
- “Information & modeling”: Down to 2% from 3% in the earlier time slot.

The remaining four topics have practically not changed in terms of number of projects.

Number of projects in topical clusters



Source: Own calculation, see table above “Number of projects in topical clusters”

A similar picture evolves when analyzing the budgetary strength of the topical clusters (see table "Budget of projects in topical clusters"). Here again, the top-three clusters are "Unconventional Devices" (with a budget of 75,5 Mio Euros or 23 percent of the total budget of this sample), "Bio- & Neuro-ICT" and "AI & Cognition".

Budget of projects in topical clusters

Topics in FET	Budget of current projects in Mio Euros	Current projects budget share	Older projects budget share
Unconventional devices	75,5	23	23
Bio- & Neuro-ICT	57,4	18	13
AI & Cognition	35,7	11	3
Human-Computer-Interaction	35,5	11	8
Complexity	31,8	10	10
Quantum & Photonics	31,1	10	14
Green Computing & Networking	15,9	5	3
Computer Science	15,0	5	12
Computing architectures	14,8	4	5
Robotics	7,2	2	5
Information & Modeling	5,3	2	3

„Current projects" refers to FET projects which ended in 2015 and which will end 2016+, n=132.
„Older projects" refers to FET projects which ended between 2011-2014, n=130,
without CSAs, missing cluster „Practices & Communication" has only 2 projects which are both CSAs.

Comparing the budget shares of the current with the older sample we see the following three clusters with a stronger increase:

- "AI & Cognition": Budget wise, this topic currently is responsible for 11% of the overall budget compared to only 3% in the earlier sample.
- "Bio-& Neuro-ICT": Up from 13% to 18% in the current sample,
- "Human-Computer-Interaction": Up from 8% to 11% in the current sample, and
- "Green Computing and Networking": With a slight increase from 3 to 5% in the current sample.

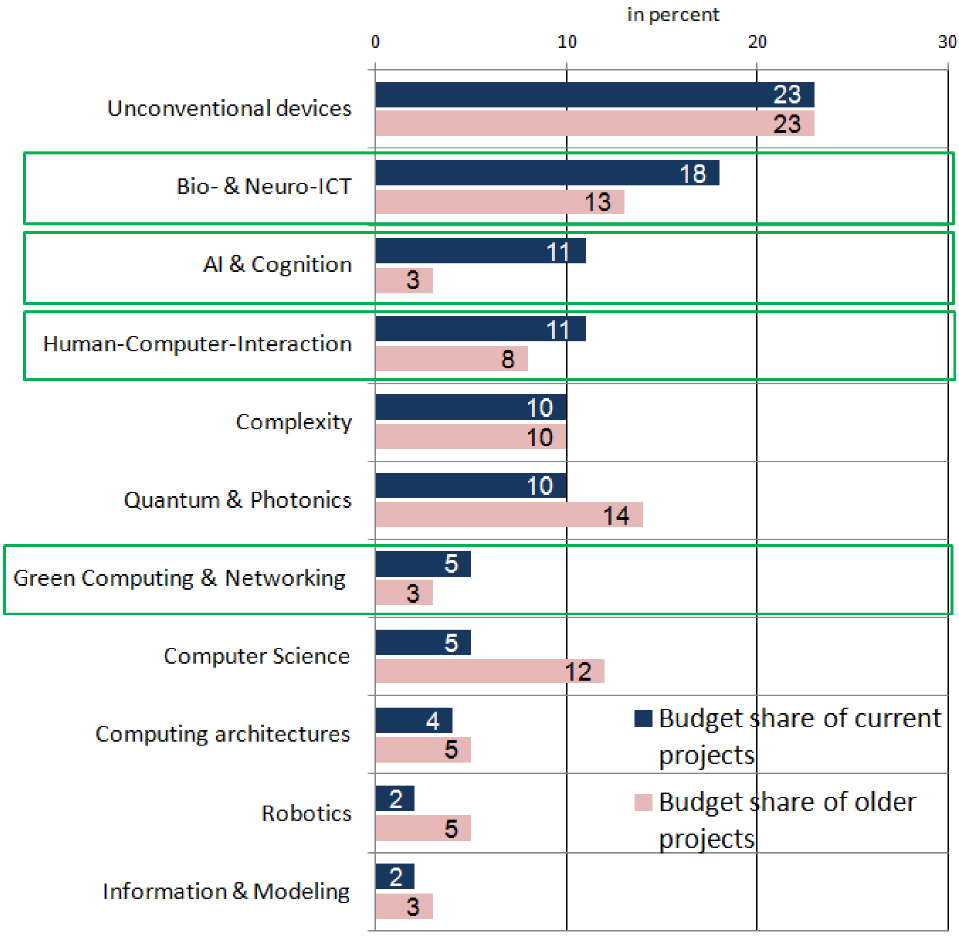
The most dynamic fields are marked with a green frame in the figure "Budget of projects in topical clusters".

On the other hand, there are two clusters which have experienced a decline in terms of budgetary size. These are:

- "Computer Science": Being responsible for only 5% of the total budget in the current sample as compared to 12% in the earlier sample, and
- "Quantum & Photonics", which consumes 10% in the current sample as compared to 14% in the earlier sample.
- Robotics: Coming down to 2% as compared to 5% in the earlier sample.

The remaining four topics have practically not changed in terms of number of projects.

Budget of projects in topical clusters

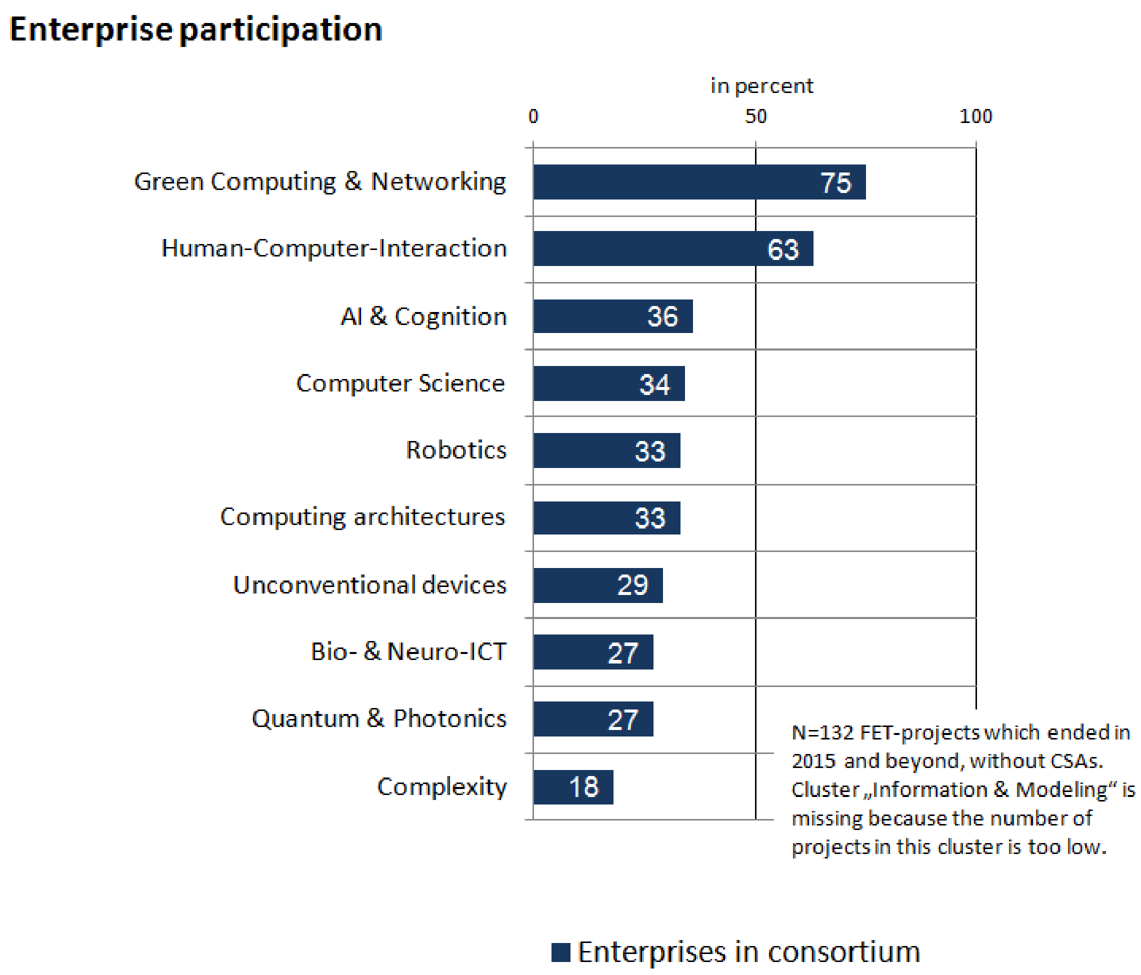


Source: Own calculation, see table above "Budget of projects in topical clusters"

2.2 Enterprise participation

One or more enterprises as participants in a FET project indicate a certain relevance of the idea or development in economic terms. It may also indicate the start of an innovation eco-system because enterprises are usually pushing commercialization potentials of the technology being developed in the FET project.

Concerning enterprise participation in the current FET sample, we see the following results: The clusters "Green Computing & Networking" and "Human-Computer-Interaction" display the highest share of enterprise participation with 75% respectively 63% (see chart "Enterprise participation"). It has to be noted that these are rather small clusters with only 8 respectively 6 projects in the current sample (The top three clusters contain 26, 17 and 11 projects).



Conversely, the topics with a relatively low level of enterprise participation are:

- "Unconventional devices" as the most important cluster by numbers and by budget share but with only 29 % enterprise participation, and
- "Bio-& Neuro-ICT" being second according to numbers and budget share but only displaying an enterprise participation of 27%.

Interestingly, the cluster "AI & Cognition" is the only cluster ranked high according to numbers and budget share and at the same time displaying a high enterprise participation (third in size and third in enterprise participation).

2.3 Degree of cross-disciplinarity research in each cluster

FET projects are cross-disciplinary projects by design. The combination of different disciplines or research fields is one of the criteria in the review process of the project proposals and characterizes FET projects as such. The assumption is that cross-disciplinary research is at the same time research which displays a high novelty value. This assumption is supported by research findings in science technology studies which found that novel and dynamic research topics predominantly develop at the boundaries of established disciplines and through cross-disciplinary co-operations[2].

Also, from a conceptional point of view, cross-disciplinary research approaches are seen as appropriate ways to "produce significant results because they bring new perspectives and new tools to the study of problems in an existing discipline. The resulting capacity to 'see differently', compared to traditional approaches, is associated with increased creativity and innovation", as research programme evaluators Wagner and Alexander put it.[3]

Stating that FET projects are interdisciplinary by design does not mean that they are all interdisciplinary to the same extent. In fact, we observe different levels of

2 Reiss, Thomas; Schmoch, Ulrich; Schubert, Torben et. Al (2007): R&D pipeline in biotechnology (German: Aussichtsreiche Zukunftsfelder der Biotechnologie. Neue Ansätze der Technologievorausschau. Karlsruhe: Fraunhofer IRB.

3 Wagner, Caroline, S.; Alexander, Jeffrey (2013): Evaluating transformative research programmes: A case study of the NSF Small Grants for Exploratory Research programme. In: Research Evaluation 22, p. 196. In this passage, the authors cite Seely-Brown, John (1997): Seeing Differently: Insights on Innovation. Boston: Harvard Business School Press.

interdisciplinarity in the different FET projects. In a rough approximation we assume that projects with a wide disciplinary stretch are at the same time projects with a high novelty value.

To determine the disciplinary stretch we analysed each of the 132 FET projects in the observe sample by noting down the participant´s disciplinary affiliation (discipline and / or research field as denoted by department, university chair, in cases of doubt: education of the lead researcher of the institution) retrieving the information manually from the respective project websites.

Looking at the spectrum of participating disciplines and research fields we determined two levels of interdisciplinarity: “medium” and “high”. In fact there was no need to define a “low” level of interdisciplinarity because all of the projects displayed at least some kind of interdisciplinarity from reasons mentioned above.

Of all 132 projects in the sample, 62 (47%) were ranked middle and 70 (53%) were ranked high. The following table shows the percentage of projects with “high” interdisciplinarity in each topical cluster.

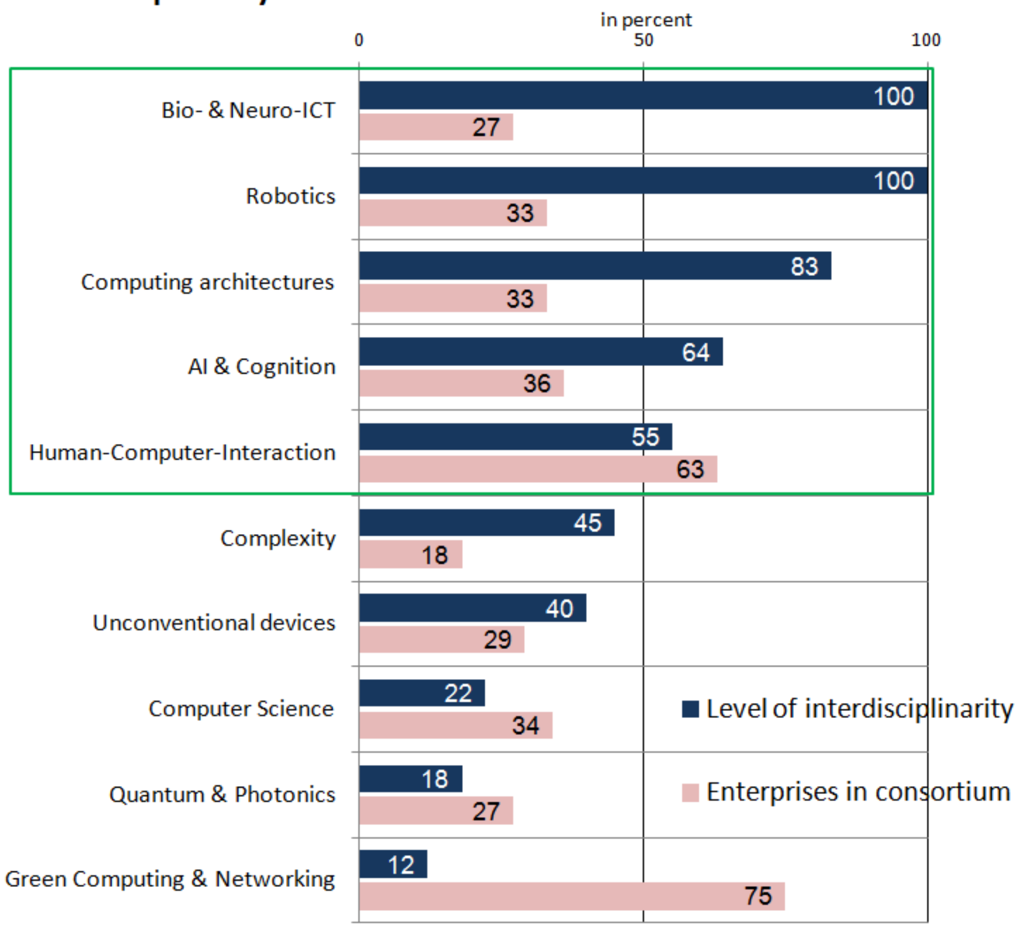
Level of interdisciplinarity and enterprise participation

Topics in FET	Percentage of projects with “high” interdisciplinarity
Bio- & Neuro-ICT	100
Robotics	100
Computing architectures	83
AI & Cognition	64
Human-Computer-Interaction	55
Complexity	45
Unconventional devices	40
Computer Science	22
Quantum & Photonics	18
Green Computing & Networking	12
Information & Modeling	-

Based on a manual assessment of the 132 FET-projects which ended in 2015 and beyond, without CSAs. Cluster „Information & Modeling“ is missing because the number of projects in this cluster is too low.

Topical clusters with more than half of the projects being of high interdisciplinarity are “Bio- & Neuro-ICT”, “Robotics”, “Computing architectures”, “AI & Cognition”, and “Human-Computer-Interaction”. These clusters are highlighted with the green frame in the figure “Level of interdisciplinarity”.

Level of interdisciplinarity



Source: Own calculation.

Conversely the clusters with a lower level of interdisciplinarity are “Computer Science”, “Quantum and Photonics” and “Green Computing and Networking”. For these three clusters it is striking that the enterprise participation is comparatively high. It seems that enterprise participation occurs with a low level of interdisciplinarity which, according to our assumptions, would qualify the project idea as being not so new. The reason for this may be that enterprises usually get involved in research projects at later stages, when the idea has already shown some potential for commercial exploitation. This in turn would principally speak against the radical novelty of the idea.

This explanation can be kept up when looking at the other results: From “Bio-& Neuro-ICT” down to “Unconventional devices”, all clusters have a low percentage of enterprises in their respective consortia and at the same time display a high level of interdisciplinarity, indicating a high level of novelty. However, there is one exception, which is the cluster “Human-Computer-Interaction”: Here we find high values at both, interdisciplinarity and enterprise participation. This may signal high interest of enterprises in a genuinely interdisciplinary field which may produce radically new technologies which are simultaneously being embraced by enterprises expecting opportunities for commercial exploitation.

2.4 Most frequent disciplines/ research fields within thematic FET-clusters

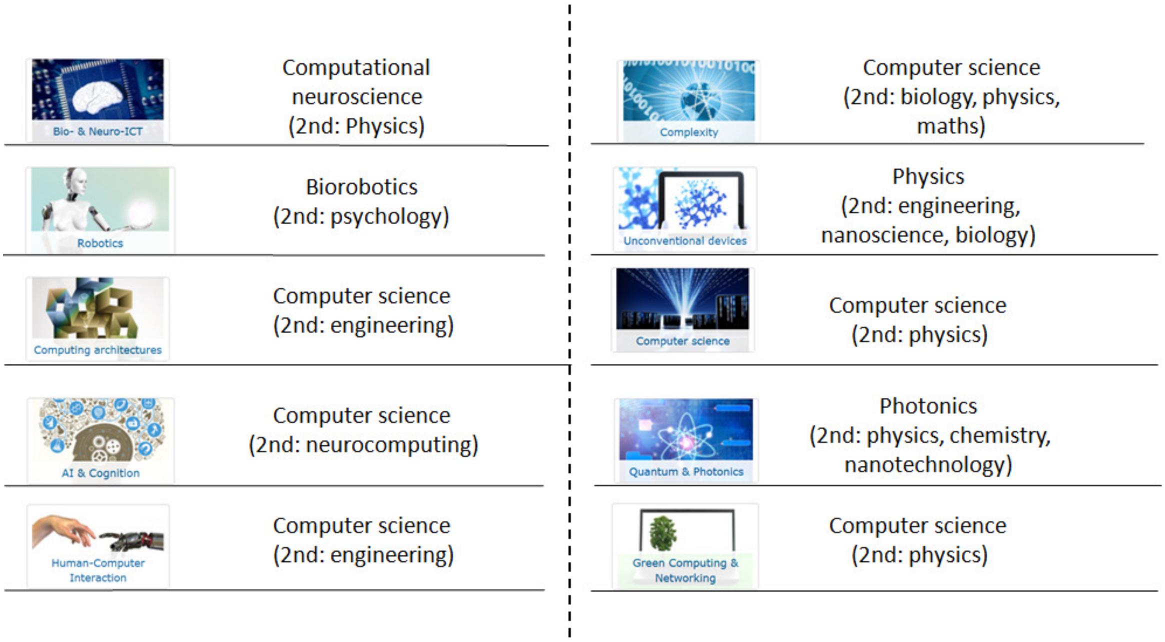
The manual assessment of the interdisciplinarity levels gives us the oppotunity to characterize the topical clusters in some more detail. As we have noted down the participating disciplines or research fields of organisations in each FET project of our sample we can analyse which disciplines or research fields are mentioned most often in each cluster.

The result of this analysis is displayed in the table “Most frequent disciplines in topical clusters”.

In the topic “Bio-& Neuro-ICT”, Computational Neuroscience is the research field we found most often. The second most frequent discipline is Physics which hints to the fact that in this cluster, many combinations between neuroscience and nanotechnology are tried. However, we would have expected to find biology on the second place, not only because of the name of the cluster which suggests inspirations from biology or biotechnology but also because the description of this cluster of the FET Unit predominantly lists projects with a strong biology part (see cluster description and project examples at the beginning of this chapter).

The co-occurrences we found in other clusters depict the design of the clusters very well, for example “Computing architectures” with Computer Science on place one and Engineering on the second place which reflects the attempt to develop a new technologies in the area of computing architectures. The same applies to the clusters “AI & Cognition”, “Human-Computer-Interaction”, and “Complexity” which all have “Computer Science” as the research field most often participating and diverse research fields with which Computer Science is combined and vice versa.

Most frequent disciplines in topical clusters



Source: Own analysis based on the determination of interdisciplinarity levels in the FET observe sample

What is striking is the frequency of “Physics” mentioned as the most relevant second discipline. This is the case in the clusters “Computational Neuroscience”, “Computer Science”, “Quantum & Photonics”, and “Green Computing & Networking”. And, in the biggest cluster “Unconventional devices”, Physics is even the most frequent discipline found in our analysis. In fact, apart from Computer Science, Physics seems to have a clear dominance in the FET projects in our sample.

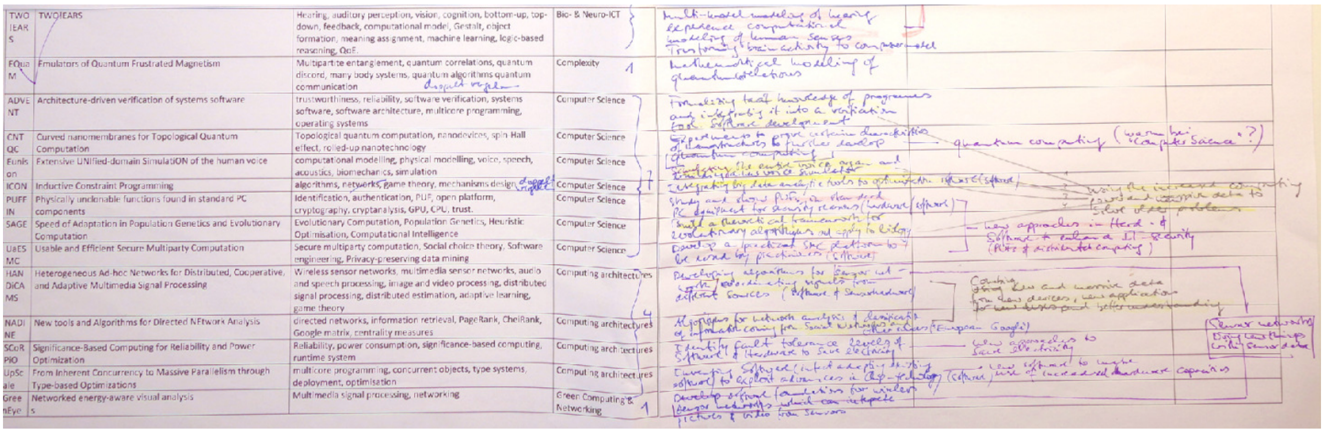
The clusters with a biology-dominance are “Robotics” and “Complexity”, whereas in “Complexity”, Biology is the second most frequent discipline together with Physics and Mathematics.

3 Bottom-up-clustering

In the observe project we use topics explored in the different FET projects as indicators for new and emerging research topics, approaches, methods, and technologies. Especially FET Open projects are seen as good indicators because researchers can select their topics freely without any restriction or predetermining focus by thematic calls (for methodological details see section 1 Introduction, samples and methods used).

Thus we consider it an exercise worthwhile to have a closer look at the research topics explored in recent FET Open projects. The clustering carried out by the FET Unit with its twelve topical clusters is used as a starting point for sorting the 67 relevant FET Open projects in our sample. Freely given keywords which were provided by the coordinators of the projects and which were made available to us by the European Commission were used as a second source. A third source for the topical investigation was the abstract for each project which is available through the Cordis database. A preliminary clustering was carried out using these sources and the final clustering was supported by other Fraunhofer experts, especially in the nano- and photonics field. The table below documents the procedure and displays cluster-building for some of the projects in our sample.

Table: Manual bottom-up clustering of research topics dealt with in FET projects



TWOEARS	TWOEARS	Hearing, auditory perception, vision, cognition, bottom-up, top-down, feedback, computational model, Gestalt, object formation, meaning assignment, machine learning, logic-based reasoning, QoE.	Bio- & Neuro-ICT
FQuaM	Emulators of Quantum Frustrated Magnetism	Multipartite entanglement, quantum correlations, quantum discord, many body systems, quantum algorithms quantum communication	Complexity
ADVENT	Architecture-driven verification of systems software	trustworthiness, reliability, software verification, systems software, software architecture, multicore programming, operating systems	Computer Science
CNTQC	Curved nanomembranes for Topological Quantum Computation	Topological quantum computation, nanodevices, spin Hall effect, rolled-up nanotechnology	Computer Science
Eunison	Extensive UNIfied-domain SimulatiON of the human voice	computational modelling, physical modelling, voice, speech, acoustics, biomechanics, simulation	Computer Science
ICON	Inductive Constraint Programming	algorithms, networks, game theory, mechanisms design	Computer Science
PUFFIN	Physically unclonable functions found in standard PC components	Identification, authentication, PUF, open platform, cryptography, cryptanalysis, GPU, CPU, trust.	Computer Science
SAGE	Speed of Adaptation in Population Genetics and Evolutionary Computation	Evolutionary Computation, Population Genetics, Heuristic Optimisation, Computational Intelligence	Computer Science
UaESMC	Usable and Efficient Secure Multiparty Computation	Secure multiparty computation, Social choice theory, Software engineering, Privacy-preserving data mining	Computer Science
HANDiCAMS	Heterogeneous Ad-hoc Networks for Distributed, Cooperative, and Adaptive Multimedia Signal Processing	Wireless sensor networks, multimedia sensor networks, audio and speech processing, image and video processing, distributed signal processing, distributed estimation, adaptive learning, game theory	Computing architectures
NADINE	New tools and Algorithms for Directed NEtwork Analysis	directed networks, information retrieval, PageRank, CheiRank, Google matrix, centrality measures	Computing architectures
SCoRPiO	Significance-Based Computing for Reliability and Power Optimization	Reliability, power consumption, significance-based computing, runtime system	Computing architectures
UpScale	From Inherent Concurrency to Massive Parallelism through Type-based Optimizations	multicore programming, concurrent objects, type systems, deployment, optimisation	Computing architectures
GreenEyes	Networked energy-aware visual analysis	Multimedia signal processing, networking	Green Computing & Networking

The aim of the bottom-up clustering was to identify new research topics which could be used as inputs for the Horizon Scanning process. These inputs are shown in the table "New research topics from the bottom-up clustering". Before presenting the results, some experiences from the clustering process shall be highlighted:

- The twelve topical clusters suggested by the European Commission which were used as a starting point for our own clustering is a rough classification which seems to follow programme-internal purposes. For a first structuring of the topics explored in the projects, the given clusters provide a good orientation. Looking more closely into the aims and methods of the projects, however, cases occurred where the assignment to the given clusters seemed not so convincing. For example we found a quantum project which was assigned to the “Computer Science”-cluster whereas our interpretation of what is being explored in this project would have justified a clear assignment to the “Quantum & Photonics”-cluster. Also, the fact that again in this sample, the “Unconventional devices”-cluster is the biggest in terms of numbers of projects indicates that projects which are difficult to classify otherwise might have been assigned to this cluster.

- Reading through the abstracts of the projects in the sample one after the other it becomes clear that interdisciplinarity is a dominant aim in all projects: In all projects there is the ambition to work in a cross-disciplinary manner and the claim that the combination of knowledge, methods and models is the most promising way to develop something new.

- It is also striking that many projects try to do something with digital mass data which have become available only recently by mobile communication devices, sensors or newly accessible data bases. We found many projects in the sample which wanted to use these data to learn something about network building and governing processes of networks. In addition, recently available mass data is being used by some FET Open projects in an attempt to solve problems which have been virulent for some time and which could not be followed further because of a lack of data.

- FET Open projects dealing with quantum- and nanotechnology explore new approaches and combinations not followed before or they try to upscale phenomena which are being observed in small scale laboratory contexts.

- Our own clustering cuts across the given FET-clustering in many ways. For example, our cluster “Bio-sensors” (see no. 3 in the table below) contains projects from the FET-cluster „Green Computing & Networking“ as well as from the FET-cluster „Computing architecture“.

3.1 List of research topics from the bottom-up clustering

In the following table we present the results of the bottom-up clustering. It has to be noted that the sample size for the clustering was relatively low (67 FET Open projects). Some of the clusters found represent the idea of very few projects and some represent the ideas of a larger series of projects exploring similar ideas. Thus, the clustering exercise not only displays similar ideas but also singular, yet interesting and unconventional new ideas.

Table: New research topics from the bottom-up clustering

1 Using biological principles and characteristics for better computing
Today, computer performance is being increased by miniaturization and optimization of available components. In the future, totally new approaches might become necessary to increase computer performance. These approaches will be inspired by biology. There are attempts to emulate biologic systems in order to enhance computer chip performance or binary communication processes. Keywords for this trend are biocomputation, bioinspired parallel computing and computational architectures using the nervous system as a blueprint.
2 Building new Brain-Machine-Interfaces (BMI) for re-programming brain cells
Although knowledge about cognitive processes has increased, it is still not clear, how brain processes really work and how they can be manipulated. One promising approach is to measure electrical brain activities in vivo and simulate activity patterns on a computer chip. Once mapped on the chip, activity patterns can be manipulated and the new pattern can be transferred to the brain using a suitable BMI. In the future this may lead to the possibility to create and delete memories.
3 Bio-sensors: Using plants as environmental sensors and connecting them to sensor networks
Plants can be used as sensors to monitor environmental parameters, such as temperature, humidity, air quality, etc. In the future, the sensing information of plants will be accessed by a technical device and the signal will be transferred over a wireless network. This way, many new applications become possible as data will be available to monitor any environment of interest.

4 Intelligent combination of sensor-data replaces traditional technologies for authorization, monitoring and observation Instead of highly visible and electricity-consuming video cameras or pattern recognition computers, sensors tracking motion, noise, temperature, weight, etc. can be used. This requires that the sensors are connected to each other and that their data is being combined in an intelligent way. New network setups and algorithms will be developed which will enable these sensor networks to identify persons, activities and objects with more precision and much less power-consumption than traditional methods.
5 Faster computers and newly available massive data hold the key for problems deemed too difficult to solve in the past. Many scientific undertakings like formalizing tacit knowledge, simulating complex organ functions or mapping evolutionary developments in biology were once considered too complex either because there was not enough data available or the computing capacity was not sufficient to run the necessary programs. With increasing computation power and the availability of new mass data which is often made automatically available by new devices many old problems can now be solved.
6 Individual hardware and software features of mobile phones and other personal computing devices will prevent these devices for being stolen in the future. New approaches for identifying computing devices (PUFs: Physical Unclonable Functions) as well as new software functions (distributed computing, automatic authorization methods) will soon be widely available. Their use enhances the grade of personalization for communication devices so that only the authorized user will be able to access these devices.
7 Smart materials will be used to provide shape-changing mobile devices and other interfaces Smart materials are designed materials that have properties that can be changed in a controlled fashion by external stimuli, such as temperature, skin contact, voice, moisture, electric or magnetic fields. In the future, mobile devices will change their appearance for example when a call or a message is being received. Also, other Human-Computer-Interfaces can change their shape, appearance and functionalities according to outer circumstances.

8 Mobile devices (smart phones, smart glasses, smart watches, etc.) will produce the data needed to finally understand and enhance human cognition, memory and behaviour. The massive data from personal smart devices will be used to decipher human cognition, and it will be used to enhance memory and possibly to govern behaviour. For example, life recording devices like Google glasses could – in combination with intelligent retrieval software – enhance the personal memory because everything the individual experiences is stored and accessible. To make this happen, advances in machine learning, Human-Computer-Interaction and software development are necessary.
9 Quantum Computing: Combining advances in quantum technology and photonics to realize a quantum computer. The next stage of computing will be quantum computing. Instead of binary digits which are used in conventional digital computers, quantum computers uses quantum bits (qubits), which can be in superpositions of states. Quantum computers is still in an early stage of development but if realized, they may be able to efficiently solve problems that no current computer would be able to solve within a reasonable amount of time. One approach to advance the development is to combine quantum technology and photonics.
10 Use recently discovered graphene characteristics to produce better switches, lasers, chips, etc. Graphen has many many extraordinary properties which are being studied worldwide, and especially in the FET Flagship on graphene in Europe. Currently there are many applications being developed and tested and in the future, graphene may trigger a new generation of better electromagnetic switches, lasers, broadband chips and so on.
11 Cancer-detection in real-time New insights in hyper-spectrography, advanced mathematical methods and the combination of available data on more than 200 kinds of cancer make it possible to discriminate between healthy and malignant tissues in real-time. This information may be used by medical doctors during surgical procedures.

12 Quantum technology will move from basic research to applications Quantum technology today is in an early stage of its development and research is often characterized by theoretical reflections. However, the promises concerning future applications are manifold and are not limited to the quantum computer. Instead, the expected applications range from secure communications, highly sensitive sensors to other breakthroughs in the context of data processing. For some researchers it is clear that the 21. Century will be the century of quantum technology.	
13 The combination of scientific advances in nanotechnology, optics and spintronics with conventional electronics will lead to new computing and switching devices with superior performance. Advances in nano-electronics, nanoscale integration, optical signal processing and spintronics are currently being combined with existing electronics (chipdesign, switching technology, storage technologies) in order to increase performance or to build all new devices based on new principles. In the future, the incremental improvements from these combinations and inventions will turn into disruptive changes in computing and high-speed applications.	
14 Advances in robotics will be achieved by combining biology, material science and computer technology. To build robots is an interdisciplinary venture by nature. In the future, efficient and broadly applicable robots will be available because research has successfully combined insights from biology (robots inspired by plants, octopus or insects, swarms of robots with emergent behaviours) and material science (evolving and shape-changing robots) has has successfully mapped those advances into information systems.	
15 Insights from cognition research and biology will enable better Ambient Intelligence (AmI) systems. Context Awareness and activity recognition are key components of the vision of Within Ambient Intelligence (AmI), a common problem is that activity recognition can only be achieved in narrowly defined sensor configurations. Bringing together insights from biology machine learning and control theory will allow new systems which take advantage of sensing modalities that happen to be available, rather than forcing the user to deploy specific, application dependent sensor systems.	

16 Micromotors will be built into nano-scale micro-electro-mechanical systems (MEMS) and enable new lab-on-a-chip systems and biomedical implants.

Researchers from different disciplines (physics, biology, medicine) have teamed up to integrate micromotors into MEMS. Once successful, this combination will allow a wide range of applications such as new lab-on-a-chip systems, pumps for micro-fluids and tuneable filters, tuneable lenses or filtering substrates for biotechnology, tissue engineering and regenerative medicine.

17 Robots will become more human-like as their vocabulary comes closer that of real humans.

Currently, computational intelligence is restricted to lexical descriptions found in dictionaries. But with current results from brain research, clinical studies and neuroimaging, a complete inventory of words, their emotional valence and perceptual properties will become available. However, it takes a combined effort of neuroscientists, cognitive scientists, lexicographers and computer scientists to harness this new source.

.

Appendices

Appendix A: List of 132 FET projects for the portfolio analysis

List of relevant projects for the observe portfolio-analysis (FET Open, FET Proactive projects ending 2015 to 2018 without CSAs, N=132)

Acronym	Title
3x3D Imaging	Fast two-photon in vivo imaging and stimulation with simultaneous three-dimensional random-access scanning in multiple brain regions
ABACUS	Parallel computing based on designed networks explored by self-propelled, biological agents
ACMOL	Electrical spin manipulation in electroACtive MOLecules
ADVENT	Architecture-driven verification of systems software
ALLOW Ensembles	ALLOW Ensembles
ASCENS	Autonomic Service-Component Ensembles
ASSISI_bf	Animal and robot Societies Self-organise and Integrate by Social Interaction
BAMBI	Bottom-up Approaches to Machines dedicated to Bayesian Inference
BBOI	Breaking the Barrier on Optical Integration
BIOMICS	Biological and Mathematical Basis of Interaction Computing
BioMot	Smart Wearable Robots with Bioinspired Sensory-Motor Skills
BOC	The Body-on-a-Chip (BoC)
BRAINBOW	Linking biological and artificial neuronal assemblies to restore lost brain functions: towards the design of innovative bi-directional neuroprostheses
BRAINLEAP	A quantum leap: from a spike-centered brain universe to its underlying synaptic landscape
BrainScaleS	Brain-inspired multiscale computation in neuromorphic hybrid systems
BRISQ2	Bright Squeezed Vacuum and its Applications
CARTOON	CARbon nanoTube phOtONic devices on silicon

CASSTING	Collective Adaptive System SynThesIs with Non-zero-sum Games
CEEDs	The Collective Experience of Empathic Data Systems
CNTQC	Curved nanomembranes for Topological Quantum Computation
COINVENT	Concept Invention Theory
ConCreTe	Concept Creation Technology
CONGAS	Dynamics and COevolution in Multi-Level Strategic INteraction GAmeS
CORONET	Choreographing neural networks: coupling attractor dynamics and state-dependent computations across biomimetic brain interfaces with neuromorphic VLSI
CORTICONIC	Computations and Organization of Retes Through the Interaction of Computational, Optical and Neurophysiological Investigations of the Cerebral cortex
DIADEMS	DIAmond Devices Enabled Metrology and Sensing
DIVERSIFY	DIVERSIFY : Ecology-inspired software diversity for distributed adaptation in CAS
EASEL	Expressive Agents for Symbiotic Education and Learning
ENLIGHTENMENT	Exploring the neural coding in behaving animals by novel optogenetic, high-density microrecordings and computational approaches: Towards cognitive Brain-Computer Interfaces
ENTRA	Whole-Systems Energy Transparency
EQuaM	Emulators of Quantum Frustrated Magnetism
Eunison	Extensive UNIfied-domain SimulatiON of the human voice
EVOBLISS	Technological Evolution of Synergy Between Physicochemical and Living Systems
EvoEvo	Evolution of Evolution
EVOPROG	General-Purpose Programmable Evolution Machine on a Chip
EXA2GREEN	Energy-Aware Sustainable Computing on Future Technology – Paving the Road to Exascale Computing
GEMINI	GErmanium MId-infrared plasmoNIcs for sensing
GHOST	Generic and Highly Organic, Shape-changing inTerfaces
GOSFEL	GRAPHENE ON SILICON FREE ELECTRON LASER
GRAPHENICS	Graphene-enabled on-chip supercontinuum light sources
GRASP	GRAPHENE-BASED SINGLE-PHOTON NONLINEAR OPTICAL DEVICES
GreenEyes	Networked energy-aware visual analysis
GRIDMAP	Grid cells: From brains to technical implementation
HAIRS	Hybrid Architecture for quantum Information using Rydberg ensembles and Superconductors
HANAS	Hybrid Artificial and Natural Atomic Systems
HANDiCAMS	Heterogeneous Ad-hoc Networks for Distributed, Cooperative, and Adaptive Multimedia Signal Processing
Harvest4D	Harvesting Dynamic 3D Worlds from Commodity Sensor Clouds

HELiCoiD	HypErspectraL Imaging Cancer Detection
HIDO	Holographic Integrated Display and Optics
HIERATIC	Hierarchical Analysis of Complex Dynamical Systems
ICON	Inductive Constraint Programming
INFERNOS	Information, Fluctuations, and Energy Control in Small Systems
INSIGHT	INSIGHT - DARWINIAN NEURODYNAMICS
InSpin	Insulator Spintronics
iQIT	Integrated Quantum Information Technology
iQUOEMS	Interfacing Quantum Optical, Electrical, and Mechanical Systems
i-RISC	Innovative Reliable Chip Designs from Low-Powered Unreliable Components
LANDAUER	Operating ICT basic switches below the Landauer limit
LASAGNE	multi-LAyer SpAtiotemporal Generalized NEtworks
Lrn2Cre8	Learning to Create
MAGNETRODES	Electromagnetic detection of neural activity at cellular resolution
MANAQA	Magnetic Nano Actuators for Quantitative Analysis
MATHEMACS	MATHEmatics of Multi-level Anticipatory Complex Systems
MatterWave	A Guided Matter-Wave Interferometer on a Atom-Chip
MICREAGENTS	Microscale Chemically Reactive Electronic Agents
MindSee	Symbiotic Mind Computer Interaction for Information Seeking
MINIMAL	Miniature Insect Model for Active Learning
MOLARNET	Molecular Architectures for QCA-inspired Boolean Networks
MoQuaS	Molecular Quantum Spintronics
MULTI	MULTI-valued and parallel molecular logic
MULTIPLEX	Foundational Research on MULTIlevel comPLEX networks and systems
MUSE	Machine Understanding for interactive StorytElling
NADINE	New tools and Algorithms for Directed NEtwork Analysis
NANOQUESTFIT	Nanoparticles in Quantum Experiments: Exploring the scientific basis of future innovative quantum technologies
NASCENCE	NAnoSCale Engineering for Novel Computation using Evolution (NASCENCE)
NEBIAS	NEurocontrolled BIdirectional Artificial upper limb and hand prosthesiS
NeuroSeeker	Investigation of local and global cortical circuits with advanced neural probes for high-resolution electrophysiological monitoring and optogenetic stimulation
PAMS	Planar Atomic and Molecular Scale devices
PAPETS	Phonon-Assisted Processes for Energy Transfer and Sensing
ParaDIME	Parallel Distributed Infrastructure for Minimization of Energy
PHIDIAS	Ultra-Low-Power Holistic Design for Smart Biosignals Computing Platforms

PhyChip	Physarum Chip: Growing Computers from Slime Mould
PLANTOID	Innovative Robotic Artefacts Inspired by Plant Roots for Soil Monitoring
PLASWIRES	Engineering multicellular biocircuits: programming cell-cell communication using plasmids as wires
PLEASED	PLants Employed As SEnsor Devices
PLEXMATH	Mathematical framework for multiplex networks
PROMISCE	Quantum Propagating Microwaves in Strongly Coupled Environments
PUFFIN	Physically unclonable functions found in standard PC components
QALGO	Quantum Algorithmics
QUANTICOL	A Quantitative Approach to Management and Design of Collective and Adaptive Behaviours
QuILMI	Quantum Integrated Light Matter Interface
qwad	Quantum Waveguides Application and Development
RAMP	Real neurons-nanoelectronics Architecture with Memristive Plasticity
RAMPLAS	100 Gb/s Optical RAM on-chip: Silicon-based, integrated Optical RAM enabling High-Speed Applications in Computing and Communications
RAQUEL	Randomness and Quantum Entanglement
Recall	RECALL: Enhanced Human Memory
RENVISION	Retina-inspired ENcoding for advanced VISION tasks
RiboNets	Programming cellular networks and community behaviour with synthetic RNA-based devices
SAGE	Speed of Adaptation in Population Genetics and Evolutionary Computation
ScaleQIT	Scalable Superconducting Processors for Entangled Quantum Information Technology
SceneNet	Mobile Crowd Sourcing Video Scene Reconstruction
SCoRPiO	Significance-Based Computing for Reliability and Power Optimization
SE2ND	Source of Electron Entanglement in Nano Devices
SeeBetter	Seeing Better with Hybrid BSI Spatio-Temporal Silicon Retina
SENSATION	Self Energy-Supporting Autonomous Computation
Si elegans	Emulating the C. elegans nervous system: A blueprint for brain-inspired computational architectures
SiAM	Silicon at the Atomic and Molecular scale
SI-CODE	Towards new Brain-Machine Interfaces: state-dependent information coding
SimpleSkin	Cheap, textile based whole body sensor sensing system for interaction, physiological monitoring and activity recognition
SIQS	Simulators and Interfaces with Quantum Systems
SiSPIN	Silicon Platform for Quantum Spintronics

SkAT-VG	Sketching Audio Technologies using Vocalizations and Gestures
SmartSociety	Hybrid and Diversity-Aware Collective Adaptive Systems: When People Meet Machines to Build a Smarter Society
Sophocles	Self-Organised information PrOcessing, CriticaLity and Emergence in multilevel Systems
SpaceCog	Spatial Cognition
SPANGL4Q	Spin-Photon Angular Momentum Transfer for Quantum-Enabled Technologies
SWARM-ORGAN	A theoretical framework for swarms of GRN-controlled agents which display adaptive tissue-like organisation
Symbitron	Symbiotic man-machine interactions in wearable exoskeletons to enhance mobility for paraplegics
SYMONE	SYnaptic MOlecular NEtworks for Bio-inspired Information Processing
TERACOMB	Quantum Cascade Lasers Based TERAhertz Frequency COMB
TherMiQ	Thermodynamics of Mesoscopic Quantum Systems
TOLOP	Towards Low Power ICT
TOPDRIM	Topology driven methods for complex systems
TOPOSYS	Topological Complex Systems
TWO!EARS	TWO!EARS
UaESMC	Usable and Efficient Secure Multiparty Computation
UPGRADE	bottom-UP blueprinting GRAphene baseD Electronics
UpScale	From Inherent Concurrency to Massive Parallelism through Type-based Optimizations
VERE	Virtual Embodiment and Robotic Re-Embodiment
VISUALISE	VISUAL MODELLING USING GANGLION CELLS
WASPS	Wavelength tunable Advanced Single Photon Sources
WHIM	The What-If Machine

Appendix B: List of 67 FET Open projects for the bottom-up clustering

(FET Open, FET in SME and Young Explorers ending 2015-2018)

Acronym	Title	Proposal Free Keywords (from EU database)	Topic (given by FET unit)
3x3D Imaging	Fast two-photon in vivo imaging and stimulation with simultaneous three-dimensional random-access scanning in multiple brain regions	two-photon microscopy, three-dimensional imaging, in vivo, neuronal network, dendritic imaging, visual cortex, laser scanning, large tissue volume, ultrafast lasers, retina, visual system, thalamus	AI & Cognition
MINIMAL	Miniature Insect Model for Active Learning	Minimal cells, biomolecular networks, biocomputational model, artificial eukaryotic cells	AI & Cognition
MUSE	Machine Understanding for interactive StorytElling	interactive virtual worlds, natural language understanding, knowledge representation	AI & Cognition
ABACUS	Parallel computing based on designed networks explored by self-propelled, biological agents	biocomputation, parallel computing, unconventional computing, NP-hard problems, molecular motors, bacteria, fungi, microfluidics, nanofluidics, nanofabrication, microtechnology	Bio- & Neuro-ICT
BOC	The Body-on-a-Chip (BoC)	Microfluidics, Tissue Spheres, 3D tissue, drug screening, pharmacology, organotypic tissue, body context	Bio- & Neuro-ICT
BRAINBOW	Linking biological and artificial neuronal assemblies to restore lost brain functions: towards the design of innovative bi-directional neuroprostheses	lesion, coding, decoding, multichannel, electrophysiology	Bio- & Neuro-ICT
BRAINLEAP	A quantum leap: from a spike-centered brain universe to its underlying synaptic landscape	neuroengineering; cortical neurobiology; spike; intracellular recordings; extracellular electrodes; multielectrode arrays; microtechnology; microfabrication; brain-machine interfacing	Bio- & Neuro-ICT

ENLIGHTEN MENT	Exploring the neural coding in behaving animals by novel optogenetic, high-density microrecordings and computational approaches: Towards cognitive Brain-Computer Interfaces	neurocomputation, brain connectivity, optogenetics, high-density recordings, BCI	Bio- & Neuro-ICT
INSIGHT	INSIGHT - DARWINIAN NEURODYNAMICS	Neural implementations of evolutionary dynamics, insight problem solving, large problem space search, evolutionary and autonomous robotics, fluid construction grammar	Bio- & Neuro-ICT
PLEASED	PLants Employed As SEnsor Devices	Bio-sensors, Plants signal, Ecosystem, Plant behavior, Plant communities	Bio- & Neuro-ICT
TWO!EARS	TWO!EARS	Hearing, auditory perception, vision, cognition, bottom-up, top-down, feedback, computational model, Gestalt, object formation, meaning assignment, machine learning, logic-based reasoning, QoE.	Bio- & Neuro-ICT
EQuaM	Emulators of Quantum Frustrated Magnetism	Complex quantum systems. Spin liquids and topological order. Atomic and optical quantum emulators. Future and emerging quantum technologies.	Complexity
ADVENT	Architecture-driven verification of systems software	trustworthiness, reliability, software verification, systems software, software architecture, multicore programming, operating systems	Computer Science
CNTQC	Curved nanomembranes for Topological Quantum Computation	Topological quantum computation, nanodevices, spin-Hall effect, rolled-up nanotechnology	Computer Science
Eunison	Extensive UNIfied-domain SimulatiON of the human voice	computational modelling, physical modelling, voice, speech, acoustics, biomechanics, simulation	Computer Science
ICON	Inductive Constraint Programming	Constraint programming, data mining, constraint satisfaction, scheduling, machine learning	Computer Science

PUFFIN	Physically unclonable functions found in standard PC components	Identification, authentication, PUF, open platform, cryptography, cryptanalysis, GPU, CPU, trust.	Computer Science
SAGE	Speed of Adaptation in Population Genetics and Evolutionary Computation	Evolutionary Computation, Population Genetics, Heuristic Optimisation, Computational Intelligence	Computer Science
UaESMC	Usable and Efficient Secure Multiparty Computation	Secure multiparty computation, Social choice theory, Software engineering, Privacy-preserving data mining	Computer Science
HANDiCAMS	Heterogeneous Ad-hoc Networks for Distributed, Cooperative, and Adaptive Multimedia Signal Processing	Wireless sensor networks, multimedia sensor networks, audio and speech processing, image and video processing, distributed signal processing, distributed estimation, adaptive learning, game theory	Computing architectures
NADINE	New tools and Algorithms for Directed NEtwork Analysis	directed networks, information retrieval, PageRank, CheiRank, Google matrix, centrality measures	Computing architectures
SCoRPiO	Significance-Based Computing for Reliability and Power Optimization	Reliability, power consumption, significance-based computing, runtime system	Computing architectures
UpScale	From Inherent Concurrency to Massive Parallelism through Type-based Optimizations	multicore programming, concurrent objects, type systems, deployment, optimisation	Computing architectures
GreenEyes	Networked energy-aware visual analysis	Multimedia signal processing, networking	Green Computing & Networking
GHOST	Generic and Highly Organic, Shape-changing inTerfaces	user interfaces, human-computer interaction, multitouch, shape-changing interfaces, user experience, interaction design, organic user interfaces, actuators, shape displays, non-WIMP interfaces	Human-Computer Interaction
HIDO	Holographic Integrated Display and Optics	Head Mount Display Augmented Reality Display OLED	Human-Computer Interaction

Recall	RECALL: Enhanced Human Memory	Pervasive computing, human augmentation	Human-Computer Interaction
SceneNet	Mobile Crowd Sourcing Video Scene Reconstruction	3D video reconstruction, crowd sourcing, social networks, mobile platforms, parallel computing	Human-Computer Interaction
SI-CODE	Towards new Brain-Machine Interfaces: state-dependent information coding	Bidirectional Brain Machine Interfaces; neural decoding; electrical brain stimulation; Neuromorphic VLSI devices, in-vivo experiments, in vitro experiments, multi-scale analysis	Human-Computer Interaction
SimpleSkin	Cheap, textile based whole body sensor sensing system for interaction, physiological monitoring and activity recognition	smart textiles, activity recognition, HCI, lifestyle monitoring, mobile systems	Human-Computer Interaction
SkAT-VG	Sketching Audio Technologies using Vocalizations and Gestures	Sketching, sound design, vocal production, manual gestures, auditory cognition, machine learning, audio technologies	Human-Computer Interaction
Harvest4D	Harvesting Dynamic 3D Worlds from Commodity Sensor Clouds	3d acquisition, laser scanning, image capture, crowd sourcing data	Information & Modeling
EYE	Empowering Young Explorers	reinforcing participation of young researchers in FET; cycles of brainstorming events; social networking platform; training, mentoring and master classes; mobilisation	Practices & Communities
BBOI	Breaking the Barrier on Optical Integration	Photonics Integrated circuits; Silicon Photonics; Adaptive optical signal processing; Nano-ionic resistive switching materials; Solid state electrochemistry; Impedance detection	Quantum & Photonics
HAIRS	Hybrid Architecture for quantum Information using Rydberg ensembles and Superconductors	Rydberg atoms - collective coupling - entanglement - hybrid architecture - superconducting circuit - cold atoms - dipole interactions - surface - electric field	Quantum & Photonics

iQIT	Integrated Quantum Information Technology	Quantum Information Science, Integrated Technolgy, Circuit Quantum Electrodynamics, Trapped Ions	Quantum & Photonics
iQUOEMS	Interfacing Quantum Optical, Electrical, and Mechanical Systems	quantum interface, optical and microwave communications, nanomechanical resonators	Quantum & Photonics
QUAINT	Optimal Control Technologies in Quantum Information Processing	quantum information processing; quantum optimal control;	Quantum & Photonics
QuILMI	Quantum Integrated Light Matter Interface	integrated quantum device, ultra cold atoms, single photons, hybrid systems	Quantum & Photonics
PLANTOID	Innovative Robotic Artefacts Inspired by Plant Roots for Soil Monitoring	Bio-robotics, Bio-mimetic robotics, Sensors, Actuators, Bio-inspired processing, Distributed Intelligence, Plants	Robotics
RoboSoft	A Coordination Action for Soft Robotics	Soft robotics, smart materials, soft actuators, morphological computation	Robotics
ACMOL	Electrical spin manipulation in electroACtive MOLecules	Switchable spin-polarizer, electroactive molecules, electric field, three-terminal devices, molecular spintronics and graphene.	Unconventional devices
BAMBI	Bottom-up Approaches to Machines dedicat-ed to Bayesian Inference	Bayesian inference, cell signalling, stochsatic electronics	Unconventional devices
BRISQ2	Bright Squeezed Vacuum and its Applications	quantum information, bright squeezed vacuum, quantum key distribution, entanglement, Bell inequality violation	Unconventional devices
CARTOON	CARbon nanoTube phOtONic devices on sili-con	Carbon nanotubes, silicon photonics, optoelectronics, nanosource, integrated optics, hybrid integration, nanophotonics	Unconventional devices
GEMINI	GErmanium MId-infrared plasmoNIcs for sensing	Plasmonics, group-IV photonics, germanium, silicon, infrared spectroscopy, infrared sensing, optical antennas	Unconventional devices
GOSFEL	GRAPHENE ON SILICON FREE ELECTRON	Graphene, laser, terahertz	Unconventional

	LASER		devices
GRAPHENICS	Graphene-enabled on-chip supercontinuum light sources	integrated nonlinear optics, supercontinuum generation, graphene-covered silicon waveguides, second- and third-order nonlinearity, standard waveguide design, mid-infrared modelocked fiber pump laser	Unconventional devices
GRASP	GRAPHENE-BASED SINGLE-PHOTON NONLINEAR OPTICAL DEVICES	nonlinear optics, graphene, plasmonics, quantum information, nano-photonics	Unconventional devices
HELiCoiD	HypErspectraL Imaging Cancer Detection	Hyper-spectral imaging, cancer detection, tumour discrimination, real-time system implementations, in-vivo surgery guidance	Unconventional devices
INFERNOS	Information, Fluctuations, and Energy Control in Small Systems	information to energy conversion, Maxwell's Demon, nanoparticles, biomolecules, single-electron devices, fluctuations, non-equilibrium work relations, quantum measurements	Unconventional devices
InSpin	Insulator Spintronics	Nano-electronics, magneto-electronics, spintronics, spin-dependent transport, magnetic nanostructures, spin-wave bus, STT-MRAM, spin-torque oscillators	Unconventional devices
i-RISC	Innovative Reliable Chip Designs from Low-Powered Unreliable Components	fault tolerance, nanoscale integration, low-powered chip, error correcting codes, fault-tolerant codecs, in-chip coding, reliable storage and transport, reliable synthesis	Unconventional devices
MANAQA	Magnetic Nano Actuators for Quantitative Analysis	Magnetic Manipulation, Proteins and macromolecules, Single-Molecule Conductance	Unconventional devices
NANOQUESTFIT	Nanoparticles in Quantum Experiments: Exploring the scientific basis of future innovative quantum technologies	Foundations of quantum science and technology, Quantum-classical transition, Decoherence, Nanoparticle technologies, Quantum enhanced measurements	Unconventional devices
PAPETS	Phonon-Assisted Processes for Energy Transfer and Sensing	Open quantum systems, quantum biology, phonon-assisted processes, photosynthesis, olfaction, quantum information.	Unconventional devices

PROMISCE	Quantum Propagating Microwaves in Strongly Coupled Environments	Quantum circuits, microwave photons, quantum computation, quantum communication, quantum simulation, all optical quantum computing	Unconventional devices
RAMPLAS	100 Gb/s Optical RAM on-chip: Silicon-based, integrated Optical RAM enabling High-Speed Applications in Computing and Communications	optical RAM, optical interconnects, computing, communications, optical routing, optical signal processing	Unconventional devices
RAQUEL	Randomness and Quantum Entanglement	quantum information processing; randomness; pseudorandomness; entanglement; cryptography; randomness extractors; unitary k-designs; random matrices; random channels; random circuits	Unconventional devices
RiboNets	Programming cellular networks and community behaviour with synthetic RNA-based devices	RNA synthetic programming	Unconventional devices
SE2ND	Source of Electron Entanglement in Nano Devices	nanoelectronics, hybrid devices, quantum technology, quantum electronics, quantum dots	Unconventional devices
SiSPIN	Silicon Platform for Quantum Spintronics	silicon-germanium, semiconductor nanowires, self-assembled quantum dots, SiGe-on-Insulator, spin qubit, spin transistor, spin-orbit interaction, hole devices, quantum spintronics, nanoelectronics	Unconventional devices
SPANGL4Q	Spin-Photon Angular Momentum Transfer for Quantum-Enabled Technologies	quantum technologies, spintronics, quantum photonics, nanophotonics, optical vortices, optical angular momentum	Unconventional devices
TERACOMB	Quantum Cascade Lasers Based TERAhertz Frequency COMB	terahertz, semiconductor lasers, frequency combs, mode-locking, quantum cascade lasers, intersubband transitions, fiber lasers, semiconductor amplifiers, frequency metrology, frequency standards	Unconventional devices
TherMiQ	Thermodynamics of Mesoscopic Quantum	Quantum mesoscopic systems; Quantum information pro-	Unconventional

	Systems	cessing; Quantum Optics; Quantum Thermodynamics; Quantum optomechanics; Ultracold atoms; Quantum many-body systems.	devices
UPGRADE	bottom-UP blueprinting GRAphene baseD Electronics	Graphene Nanoribbons (GNRs), Field-Effect Transistors, Bottom-up nanofabrication, Electronics	Unconventional devices
WASPS	Wavelength tunable Advanced Single Photon Sources	Quantum communications, quantum computing, photonics	Unconventional devices