D4.4 Strategic Roadmap on Industry Engagement

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1. Introduction

A key strategic outcome of the CIRCLE consortium is to identify the status, needs, and strategy for Industry engagement. Being the ultimate objective of the CIRCLE consortium to coordinate and harmonize research activities in the emergent field of Molecular Communications, it requires a tight interplay between research activities and Industry/Academia cooperation as major stakeholders, which justifies the need for this activity.

With that purpose of proposing the strategy for Industry engagement, the CIRCLE consortium has been consulting and working with relevant reseachers from Companies, both large research-centric companies (Nokia Bells Labs, ARM), smaller startups and Research Institutions with attributes of Industrial Outreach (National Research Council of Italy) both internal and external to the consortium, in order to propose a positioning about how to foster tighter harmozied cooperation between Industry and Academica in the very multidisciplinar MolCom Field.

The working group consisted of all the members of the CIRCLE consortium, in particular lead by:

- Prof. Pietro Liò (Cambridge University)

This working group has been extended, given the fertile interplay of MolCom with the fields of Computational Biology and Synthetic Biology, Bioengineering and Medicine, with experts in such fields, namely:

- Dr. Mirela Alistar (Hasso Plattner Institute), educator and entrepeneur in Biotechnology, eHealth and MIcrofluidics
- Dr. Sheryas Shah (Nokia Bell Labs, New Jersey, US), industry researcher in nano-bio-engineering.
- Prof. Filippo Castiglione (Institute for Computing Applications, National Research Council of Italy), computational biology, bioinformatics, mathematical modeling, particularly for the immune system.
- Dr. Emre Ozer (ARM, UK), industry researcher and manager, in the field of new computing and communication paradigms. ARM Industry/academia liaison.
- Dr. Denis Manton (TSSG Waterford, Ireland): Research manager

This document exposes the outcomes of this activity, by first presenting the position of relevant actors in the field, followed by a curated description of a debate panel where the different

members were requested to start from their position and debate in pursuit of providing a development plan for Industry engagement in MolCom, both short- and mid-term.

2. Position from researchers on Industry Engagment

The 1st CIRCLE Workshop on Molecular Communications, organized by Pietro Liò in Cambridge 11–12 April 2016, included the session "*Stimulating Industry Engagement in Molecular Communications*". This session was chaired by Prof. Yifan Chen and included three presentations:

- Yifan Chen "IEEE Std 1906.1TM on Nanoscale and Molecular Communications"
- Dario Mazzella "Uptake of FET Projects – FET2RIN.com"
- Andrew Young " COMSOL – Multiphysics suite for Industry"

This session was the first attempt to incorporate MolCom in the strategic plans of companies. The organization of the session was oriented to show the potential MolCom penetration in industries, promoted by a standardization process, by the public EU funding, and by innovating products. The following discussion was very fruitful, involved the attendees significatly giving them the possibility of sharing their ideas on the MolCom expoitation in the industry.

The program of the 2nd CIRCLE Workshop on Molecular Communications, hosted by WIT in Dublin, 9–11 May 2017, included the panel "*Stimulating Industry Engagement in Molecular Communications*"[1]. The panel was chaired by Dr. Pietro Liò (Cambridge University): the other panellists were Dr. Mirela Alistar, Sheryas Shah, Filippo Castiglione, and Emre Ozer.

In comparison to the 1st CIRCLE workshop, this panel showed a significantly more mature awareness on MolCom exploitation by industries. The relevant contribution in the panel brought by important enterprises gave the audience a clear vision of the potential exploitation in the marletplace.

The different members of the CIRCLE working group for Industry Engagament were requested to present a structured and categorized proposal of main needs and bottlenecks in stablishing a roadmap for industry engagement.

They also made them available for organizing future events in collaboration with the CIRCLE beneficiaries.

In the following, a curated version of such position and vision from the researchers is presented as excerpts of slides used in working groups. The annex includes such material.

[1] https://www.youtube.com/watch?v=NCM709oRbvw

3. Description and outcomes of the debate panel

As mentioned above, the researchers of the working group devoted to establish a strategic roadmap for industry engagment met and participated in a debate panel during the second and final Workshop on Molecular Communications held in Dublin, Ireland – 9th – 11th May of 2017. The following is a curated description of their statements and position, the discussion and their task in pursuit of establishing such a Roadmap for Industry activity, including participation from an audience of researchers in MolCom from Europe, US and Asia, encompassing both Industry and Academia.

Here we provide a summary of the key statements, the dialogue and the proposed roadmap-centered actions.

The stimulating discussion was launched by the moderator, Pietro Liò, who showed some recent technologies for sequencing DNA at low cost and by easy procedures. In addion, he also noticed the microfluidics represent an important opportunity for MolCom Exploitation. This initial stimulus was promptly taken by the panellists. Emre Ozer from ARM Cambrdige proposed an analogy of DNA circuits with electronic circuits thereby stressing the need for EDA tools in the synthesis of models for nanobiocyberphysical systems enabled by MolCOM. He also mentioned the exploitation potentials brough by synthetic biology and some issues relevant to computing power. In turn, Sheryas Shah from Nokia Bell Labs in New Jersey, US, showed his perspective of MolCom exploitation with reference to nanotechnologies, neural technologies, drug therapies, and ended by hypothising the role of MolCom in driving another industrial revolution. Pharmacological potential was highlighted by Mirela Alistar, with directions of a labs with COTs components and educational aspects, also restated by Filippo Castiglione, who made some interesting example on specific applications and the relevant MolCom pathway to commoditization.

The deep involvement of the audience showed not only a marked appreciation for this initiative, but also a fruitful tendency towards exploitation. We believe that CIRCLE has provided a valuable contribution in this direction, that will be appreciated by the followup activities involving the CIRCLE beneficiaries, external researchers and, even more important, enterprises. This way, we can say that the EU is gaining a central role in the strategic MolCom exploitation thanks to CIRCLE.

Annex 1: curated description of the debate panel

Moderator (Pietro Lio, Cambridge University): I will go quickly on few slides to introduce the topics and the members of the panel and when everything will follow this kind of procedure. remember that are not to the slides we can do a sort of quick introduction about who they are so okay so industry engagement and this is very important because if we find very light connections we can boost the field. There is a one member who has been added just two minutes ago from TSSG so from and so we have Emre Ozer from ARM and is going to be the first one that will introduce why we could be interested in microfluidics and particularly molecular communication, Sheryas Shah from Nokia Bell labs and then Filippo Castiglione (National Research Council of Italy) will go through a few slides up and then there would be a short introduction from Mirela Alistar (Hasso Plattner Institute). Just to open to throw some stones in the sense to start this is something microfluidics that I was amazed to get for now for free it is a million from Oxford Nanopore in Oxford.

There is a microfluidic device and it does a DNA sequencing and so you see a mix of electronic but also digital because you read the sequence in your laptop but what you have is a lab-on-chip and I will not spend too much. This is based on a technique where an enzyme is fixed on substrate and the signal sort of five or six bases crossing the membrane gives an electric signal. What is interesting is that changing the reorienting the potential you can even have a very DNA exiting or flowing anyway in a different position and you can even discover new kind of epigenetics signals. Recently, this year, as we used to sequence the entire human genome so this together with a growing number of microfluidic devices. This is what is called sourcing one it will probably give some ideas for a garage industry or for our TVs at least so that to do you will see people with very limited amount of money being able to do experiments or even to develop new technologies that will. so this is a particularly people that are doing a sort of quantifying myself that are always looking at collecting data of different kind about body sickness of different hospitals. The idea is that you can have a sort of a model of your body to a sort of microfluidic settings where you can study the communication and sample of signals that have a different tissues and organs are exchanging. You can perhaps study aspects like cell decisions of stem cell or the aging process or how in some sense you can perhaps to better innovate with transplantation over and this is just a recently published paper and I wanted to just show the sort of a detail about believer. and this is another slide about how mathematical model could bring that with sort of design of a microfluidic and I wrote down few things but I'm not sure that these are the main challenges so I'm asking for your data and so what kind of things could be appealing for industry? because we know that model communication is central to synthetic biology, to medical areas, to

environmental, to microfluidic application so how in some sense the fact that we are so central could be exploited better and when how its very growing needs for in-body sensoring could give could be frame it into well posed questions that way industry could use. I'm receiving time-to-time emails from this is from a microfluidic company for instance and this is addressing in in Paris but others and so the at least they are trying to contact us. Okay, so we cannot say it is very fault that we have to do something and I will stop here. Emre do you want you to start and everybody can interrupt and we can have instead of a tour of the city we can in some sense exploit a more time here, much time here.

Emre Ozer (ARM, Cambridge, UK):. I'm from ARM, the research department of ARM in Cambridge in the headquarters. I am also responsible for the collaborative funded projects within the company. So, a lot of people are asking why ARM is in here, you just build semiconductor processors and so just add one slide what ARM does. so most of you know that we build processor IP we don't build chips we just design and license the IP but we have also other products from you know mobile, GPUs, ISPs, software compilers and the physical libraries as well as the most recent one is the IoT cloud platform called mbed. Some of you heard. There are hardware platforms similar to Arduino or so you can you know there's operating system RTOS you can run on it and so these are the type of the things we deliver but we are in the IP business intellectual property business mainly semiconductor but it can be in other domains as well. So it's as long as it's a well-characterized IP we are interested. So I like this analogy. This is from Georgia Tech I think a lot of you know him Ian Akyildiz. I like this analogy so the cell is very the components within a cell is very similar to a typical IoT device we build today, from control unit, memory, battery, energy harvester, etc. it's a very nice analogy but and people are actually in the synthetic biology community start building interesting examples like on the left side you see a gate on oscillators and the other circuit elements using gene DNA circuits and this on the right side is one of my favourite so they use a bacterial colony to recognize edge detection in an image. You can ask about what is the use of this but it's do you know they are scientists, they just want to make things happen. it's up to the industry to take this up and give it a more you know set the vision for this tool to have the commercial adoption. So I like to talk about you know this is our expertise semiconductor silicon chip so what is the evolution of the system abstraction and modularity. This is how we use to build system you know silicon systems today. So I'll just take you back to 70's. so we used to do you know hand design transistor level in the 70s and in the 80s we start you know the abstraction increase So we start buildings you know more gate level design and finally in the 90s we came up with this the synthesis tool so now we can write in RTL, VHDL or other favourite HDL language and the synthesis tools take care of everything and starting from the timing may not be accurate right so 2000-2005 we start building complicated chips but using the IP model. So this is one of the system-on-chips used in mobile phones. So what ARM provides is just the CPU here. You take the CPU and the rest of the IP are put together by the silicon fabless companies and they manufacture this chip in the foundry. So this is the model we use and I call

this IP component model. So let's look at the synthetic biological systems. So I'm by education computer engineer. I'm not biologists so but I did some research on the field so what is the evolution of these tools and EDA and languages. So we starting in 2000 so you start building switch level you know very simple DNA circuits and in 2010 so people are actually building more you know abstract a little more abstract modeling tools. So most recent one is the Cello tool, I think one of the speakers mentioned, maybe it was yesterday, and you can write in Verilog and build a DNA circuit. So I think this is going to happen maybe it's already happening but my prediction that we should be able to build you know this well-characterized parts and devices we should be able to build some subcellular circuits. I think it's already happening but my prediction is 2020 and after these things will happen. So what is this comparison? So an interesting thing is this is actually going faster than the silicon world. So we took from transistor to gate level it took us from transistor to our yield it took us 20 years but this community synthetic biology community is not inventing the wheel so they are just borrowing our experiences. So they actually speed this up about by about ten years. So you can today right in Verilog in your DNA circuit. Whether it is perfect, mature? That's another question. But the direction is right. This is how you build systems. So this is another thing I have noticed. so this is how we built chips more or less on there are some you know feedback loops, etc. ignoring that is the high level. We design using Verilog VHDL, we simulate. if the simulation is correct, the verification is done and then you do gate level synthesis and all the way to place a rule this is all automated now and you tape out and you normally you don't have foundry or Fab in house so you send it outside to a foundry in Taiwan TSMC and you get the chip back and also I forgot to mention the standard cell library. So there are very well characterized standard libraries people use them. I think this is happening in the synthetic biology world as well. so drawing blocks or writing in HDL and simulate it in computer before putting it on the lab and now they start characterizing the bio-parts so there are a few libraries like BioBrick iGEM and then you assembly similar to place on route to put them together and you can send a specification, I call it dry-lab-out to wet lab or wet fab. So there are companies today like Twist Bioscience or Ginkgo. So you just send specification and a week later or so you get your sample. If you're not interested in sample you they just send you the report. I mean this is how we do in silicon world. So we don't know what TSMC does when they manufacture. Once we get the chip we test it, bring it up and it works great. TSMC put things there no one knows right. So as long as the stuff you build is working this is good enough. So what else goes faster? So we know that the synthetic biology committee is borrowing a lot from us which is the right way and its going faster this abstraction so what else is going faster? So I'm sure a lot of you saw this so DNA the cost of DNA sequence is faster than the Moore's Law. So I'll have in particular in around if I am reading around 2006 to 2007 I think that was the point where the generations which happened from DNA sequencing and that speeded up the thing. So this is really good news for this community. By related also the DNA synthesis, the cost of DNA synthesis, is also going down maybe not as fast as the sequence the cost of sequencing but that's also good news because it is very

important to have very cheap sequencing and synthesis for this field to boom. So what are the opportunities? So it's just my personal view on this. so I think we will have programmable synthetic cells that will have you can use whether existing cell as a chassis or it could be completely in synthetic but I treat it as a computing storage unit so it will do some compute. It will have a lot of sensors to sense and it will have some recording device. I don't want to go in to detail so how you build this but this is just, this will eventually happen like it did a chip like that consider as a cell it will circulate in the body and it will just sense things and record and come back and report to a base station or some other device within the body and this includes also the elements of communication which is the target of this workshop and it will have a lot of uses not only in medical diagnostic but in the other sectors as well. and this is another view: we should be able to build more synthetic multicellular systems in the I wouldn't say in the near future but sometime in the future and this is my, this will be quite interesting to me actually, so as you know neural networks are extremely popular now and we are trying to build them in silicon as hardware accelerators but can we actually build a synthetic neural network at small size using synthetic neurons to understand how brain work and also build maybe a better like a synthetic artificial intelligence, I wouldn't say a brain but at least a portion of it, to understand and maybe use it as a compute device. We still don't know how all these neurons maybe, someone mentioned, one of the speakers, the astrocytes. I think they've recently found that astrocytes have a significant role in in compute. So that will help us to understand things but the question is well then? When these things will happen? So I'll give you an analogy, maybe this will give some ideas. So I know it sounds irrelevant but this is 1985 so let's do it travel 1985, Cray-2 supercomputer. I don't know if you remember, but it was quite bulky and power consumption is 200 KW and it weighed the 25 tons, it costs around 12 to17 billion and only 27 so I mean these are the public information of I found maybe you know 1 plus minus. Yeah I'll come to that so now. Let's move in you know to 2010. this is iPad-2 tablet, power consumption 5 W, dimensions it is you all of you and most of you have had this is very small, less than a kilogram, $800 at the time and 20 to 30 million sold. So, I have a question. Do they have anything in common? Anybody can answer that? What do they have in common these two systems? Computational power, yes, exactly. So the computation power I'm ignoring the fact that storage is still close to each other but the computation power in terms of gigaflops is the same so the question is: this took us 25 years to build this right from this. I could have asked the question actually, I could have asked you how many of you have a Cray-2 supercomputer today. You will probably say no but you have it. This is the 2010, your mobile phone, Samsung, iPhone are much powerful than the Cray-2 supercomputer. so my prediction is we are at this stage in the in synthetic biology we are in 1985, but with a lot of borrowing from silicon world, the experience from our you know engineers, I think we'd be working with the scientists synth biologists we can make this much faster you know. What is important is the scale. So look at the how many sold in Cray 27 very niche, right? This is niche but this is not niche (smart phones), this is commodity. So to makes synthetic biology

commodity, if we work together and you know inspired from the silicon world, borrowing from the abstractions of modularity and other engineering principles we could maybe see something more commodity. Everybody's using maybe to 2030. It's you know much faster than what we have done in the silicon world and that's it.

Shreyas Shah [Nokia Bells Labs, New Jersey, US]: I'm coming from the state New Jersey, where I am at Nokia Bell Labs and so I'm interesting perspective because as you may know Nokia Bell Labs is known to be a telecom company or nowadays it is referred to as ICT but I come from actually a biomedical engineering and a chemistry background and so I was actually working when we're talking about molecular signaling and kind of controlling cells in biology. My work was actually in trying to guide cellular behaviour and so when we look at a cell and someone spoke earlier on signals and cues that guide this behavior you have soluble cues which are like in the blood cytokines and these factors your factors are insoluble so that's more of a tissue engineering perspective. You have a scaffolding approach and you have cell-cell interactions. And so the combination of these different cues affects how a given cell in the body behaves. so in terms of a cellular response when you're looking at stem cells you're talking about differentiation when they're cancer you talk about migration and so my work as in PhD was more about using technology that is at that scale of cells to kind of control their behavior and so in this case we're talking about nanotechnology and so there's a whole nanomaterial toolkit with which I got a chance to work with. so when you look at inorganic materials whether it be something like a metallic nanoparticle, magnetic NPs, even up conversion NPs, if people have heard of this something where you actually put in low energy light and you get high energy light out, and down the other organic nanomaterials or biomaterial based substrates which are which can interface much better with the body itself as we see it. And so with that I worked in an area where I look at neural technologies so kind of combining nanomaterials with biomaterials to get this interface so when we look at for example multifunctional nanoparticles up in the top there's some work where we're using a stem cell as a carrier for example. so we put in a magnetic particle and a plasmid which was heat induced so in a presence of heat the plasmid would turn on and it would secrete a factor which was to address cancer and so the it's basically kind of combining multiple fields and you can see kind of a molecular communication aspect where you re now controlling a system which is living. And so that's more from a soluble perspective than moving to a surface where you could actually pattern a surface with different materials on different surfaces and guide behaviour. Forget about the bio the molecular aspect now, just based on the surface can you mimic those same molecular aspects so just by the shape of the surface or the stiffness of the material can you guide them and then now when you combine these two what kind of effects can you get? and so that was more from a 2d perspective soft lithography aspect then the last one was a little more of a 3d aspect so areas of optogenetics and remote drug therapies where you're using light to actually induce some sort of change in a cell or release drug and there so. this is kind of a that I came from and now when you think Nokia Bell Labs or which was formerly AT&T

believe it or not there was work going on in the bio field about a decade ago where they're playing with monkeys and rats and opening up mice and doing that type of work and there's DNA nanomotors and a lot of stuff that came out of there but traditionally even now the idea is about inventing the future of human experience as a as a bigger organization. That's how it's viewed. So 1925 is when Bell Labs started. this is State of New York at that time and always the focus was on communication from a telephone perspective but the way Bell Labs is kind of structure to think now this everyone in the company is more that you have this core need that we're going after but during that investigation if there's some general understanding that comes out. the scientists are free to kind of pursue that that goal and as a result of that what you see when you see the achievements over the 80 to 90 year history is that a lot of different technologies came out which may or may not relate to telephone or communication but something like the transistor you have on the top left side in the 40s you have the CCD camera which is on every phone now you have lasers you have UNIX you have C++ and this is all just over the years what s been what s that achieve in that time span and many might be familiar to our Father of communications Claude Shannon right so this communication this information theory we talk about the father of information theory is Claude Shannon which wrote a paper in 1948 what kind of outlining what is like the basis of which all this is built. So this is kind of what it's achieved up until now and you could see kind of the thinking behind which this is all based. and so even today I mean over the years you know this started off as AT&T then became Lucent and Alcatel-Lucent and Nokia so they've been up and downs in in terms of organizations but the core thinking and how it goes about research has pretty much been same where it's emerging much more now and what I like to just point out again there are 17 global locations. There's a location right here in Ireland which I got a chance of visits for first time but this idea of a 10x vision. so the idea that you know it's not about making an incremental change in the market that if someone has it going at a certain speed you just speed it up twice or three times. the idea is to really look from the future that is an orthogonal need for the industry and one example I like to just give there is how many people know Star Trek here maybe here and there American science fiction series from 1960s where it started and what s amazing about it is now this is I guess one notion of creativity or imagination where when you see in Star Trek they had all of these technologies in the 60s or talking to the communicator, a hollow deck, a replicator and when you see now you know you have kind of replicate of that and nowadays. we're so you have something in everyone s pocket which is a communicator right the cell phone, virtual reality, augmented reality this I don't know Pokemon Go really took off in Europe but in U.S. people kind of went crazy and some people died in flame Pokemon Go but this idea of augmented reality and near 3d printing that's going on too and then there are to say Star Trek had some more other outlandish ideas which I wouldn't say we're addressing with a specially-trained a transporter but this is what we like to see as a Bell Labs hard problems, right? This is something with the Tricorder you might have heard of the Qualcomm Tricorder competition where the idea is to build this device which in theory scans a person and it

spits out all this information medically relevant about the person so this is kind of where when we say Bell Labs hard. This is kind of the idea where you have a not just one little technology but it is how these technologies come together to form more of this network or integrated approach. And with that you know when we look at a technological revolution there have been many, right? over just the last 250 years or so and what I like to point out is when there's one side as enabling technology but the connectivity is what has a profound effect on economies in society as it grows and when you see financially for example it started with kind of the movement of money, right? Finances, then you get to the Industrial Revolution where it's actually movement of physical goods, right? With steel and steam engines it allowed for this movement of physical goods and then when you get more into this century now we're getting into that digital world, right? when you're passing first bits then you're getting two bytes we're able to pass more and more data and really when I say Bell Labs and what it's looking at Nokia it's a networking company when it comes down to the end. so this idea of a future X Network we have something with self-driving cars now right now when you have self-driving cars and you have a little gap in the network you know you could run a stop sign it can run into the guy in front right so the idea of having basically zero latency and high bandwidth that is an important factor and so I'm not going to go into all this because again I'm not even familiar with the full aspect or the breadth of this but these are aspects that Bell Labs which are being covered: all the way down from basically having self-configuring, self-optimizing networks which are accumulate all the way up to the cloud and getting up to machine learning aspect and where this comes in to where I m and now connecting my background and what Bell Labs is doing yeah it really comes down to the human Revolution. so as a human when we're talking molecular communication how is it relevant when it comes to an actual individual or the human need and so to never be offline to always have that network which is in body on body and around us so it's kind of the where does all three of those come together and so with that you know but on the one side we acquired a company called Whithings. With this we're talking more from a wearable perspective. you have a device which is measuring vital signs and the idea which is being explored is to do deep learning on this, where the deep learning comes more to the actual wearable and so it's not about raw data anymore where you recollecting so much data and no one has time to analyse it but you have these neural networks which can do that analysis on-site before it even gets to the cloud. so that's where this edge cloud computing comes into play and build one step deeper and this is kind of what where I like where I'm coming into the picture is how do we go beyond vital signs of biochemistry. so this might be the new picture if ever you wanted to take a picture of this in the next 5-10 years don't be surprised if you see people walking around the street with more and more stuff all over their body but what's fascinating with the research area is that what used to be stiff and hard with these chips its becoming more and more flexible. Stuff that are becoming right intact with the body with tattoos which do the same RF and powering. But really I think that we believe one of the key aspects that's really left is with these wearables you get vital sign measurements with

vital sign measurements. but how do you get more intimate biochemistry and so this is from the molecular communication perspective how do you tap into the communication that's happening in your body but maybe in the least invasive way to let a very facile way to kind of probe that in a continuous fashion and so with that we have a lot of interesting work going on which was already ongoing in which a few of us have brought on board we're kind of a basis of having a lab-on-chip now where it's a microfluidic system where you start integrating light and you're starting to be an electronics you get an optofluidic or you get a multi kind of system going so there's a lot of work ongoing expertise bring all this onto a chip and on the periphery you'll see other aspects that are more biological in nature whether you're actually making that droplets but actual particles would maybe that could act as sensors for instance and you have stimuli response and materials on the other end. Then you have ways of using this optoelectronics to look into the skin into the body and kind of get a sense of what is happening at the cellular and the molecular level and finally this is the last slide it's basically going beyond the five senses. We have our five senses which to which we take our input but is there a way to augment that. so you get a more into a sense of both the environment around us as well as maybe intuitive sense of inside what's going on now that's where the molecular aspect comes in. so again I've just kept a broader to give a little overview but we happy for questions and dwelling into how else we're looking at this. Thank you.

Moderator. Pietro Lio [Cambridge University]: in order to who can chop away structure on the pyre that we have seen on the edge do you suggest that we stop for a moment to introduction can we start with very heavy discussion and then we will see also the other panelists what they can offer in terms of interactions. Okay, so what are your ideas about where is the industry? Say who you are because this make, since we want to build a community that community is good that you know.

[Audience, Giacomo Morabito, University of Catania]: I liked a lot the comparison between the Moore law and what's happening right now. I don't know the field, so I mean I might be mistaken but my impression is that for what concerns the silicon case, the industry was leading these advances? I mean it was the industry mainly that was investing money and these kind of things and resources there. Obviously there was also the academic work but mostly there was industrial investment. Do you think it is the same right now with the synthetic biology case?

Emre Ozer [ARM, Cambridge, UK]: So I am new to synthetic biology but from my research what I've noticed that the big companies are very slow including the pharmaceutical companies are very slow to move into this domain and there are so many start-ups especially in the US and some in the UK around synthetic biology and they are driving this and I think the innovation will come from the small companies even though I represent a large company. I think that they are more agile, they have more freedom, they can get funding from the government and maybe in collaboration with the universities but I think the innovation will come from there.

Eduard Alarcon [UPC]: Thank you, so I would also like to react to Emre's position statement and I try to make an effort to bridge it to the audience which might be closer to the communication aspects. I think that the analogy you suggested is very valuable, I fully in second that and it also allowed forward relooking speculation and that's because the system is very similar. You have a very vertical system, very hierarchical, different levels of encapsulation of the abstraction. That's true for silicon chips of course but also true for nanobionanonetworks where the communication is either within the cell, among themselves or in a larger system whether in neurosystem, the heart or immune system. So the analogy I think is very valid and inturn you can leverage all the experience of the silicon design chip companies the very well-structured design methodology and the supporting in quote either tools for flow. what I was missing, I would like to ask you about an extension in complex chips, system on chips, you not only have computing but you do have communication from the very basic interconnect up to very sophisticated on chip networks for medical computer architectures do you have now, what I was missing in the biological counterpart is to include, to encompass also not just molecular computing and say that biology but also the molecular communication aspect, that would be of one extension of all your analogy if you wish.

Emre Ozer (ARM, Cambridge, UK): So the one of the opportunities, the first opportunity in this programmable synthetic cell, like you have a synthetic cell like a ship traveling in the bloodstream it has to have a communication so either it talks to the other Sentinel cells or it talks to a base station which is some implanted semiconductor-based recording device.

Eduard Alarcon [UPC]: Indeed, but you might agree with me that up to now …

Emre Ozer (ARM, Cambridge, UK): yes, communiction is essential and you can you can't

Eduard Alarcon [UPC]: to the synthetic biology community and even markup languages there mainly we're focused in computing aspects now. Second reflection on an analogy which I very much liked, very inspiring, the other one, about how in synthetic biology we shrink the time and evolution is faster. I support that analogy but I think that there's a unique difference. in silicon design chips stopped at 2005 we're combining juxtaposing different IP blocks allows for complex functionality but from then on now we need to take into account a variability of the process, when you take scalability into account and nowadays the paradigm is a particular opportunistic computing. You need to take into account this impair performance. A device and circuit level to achieve system-wide performance now. My reflection is that in the biological case that is intrinsic and should be taken into account upfront. Computing and communication in molecular biology is intrinsically has to be opportunistic and it's approximate. It's approximate computing in the silicon design it's approximate computing and communication in molecular biology.

Emre Ozer (ARM, Cambridge, UK): yes, so that's actually an interesting point, the approximate computing. So far the systems we build have to have as you know extremely if you know robust. That's the word. So you know we can't even tolerate a single event upset in the in the chip. This

was crazy. so now we engineers but the technology node shrinks now we start seeing these vulnerabilities and we start putting more effort on it and now there's a school in computer architecture community. They just focus on look we can't go like this. so we need to build system more app you know do you approximate computing it doesn't have to be accurate all the time and I think this is it's becoming more stochastic which is what do biological world as well.

Mirela Alistar (Hasso Plattner Institute): I'd like to simplify a little bit comparison between biological systems and computers or biology and engineering as it is at the moment. I'd like to bring it in the realm of control so it took about a thousand years or even more, thousands of years until we managed to do the transistor then until we had a couple of decades until we managed to get the computer and then once we managed to have control over it, it went faster. Now biologically we are connected to biology but we like a lot of control. Once we manage to get some control, it's going to go faster. So once we figure out a synthetic biology flow, workflow, how to manipulate genes, how to assemble them it's going to go faster. So one comments that I have apart from the control thing is you're mentioning something about pharma companies. So let me try to put it the other way around. Let's say that I come to ARM and I say I can prove in my lab, fictional, that I can use my microbiome that are the bacterium that I have on me to compute, would you use this technology instead of producing smart phones or your ARM processor or something like that?

Emre Ozer (ARM, Cambridge, UK): So no one will build an HP supercomputer using biology. This is really stupid try. So biology works slowly but if yeah but I can build a biological compute unit that can go into your body and monitor sense you? This is more efficient than putting a silicon-based chip that it's being digested by your system, right? Which one will be more reliable? The application matters. I mean no one will ever build a supercomputer using living cells.

Filippo Castiglione (National Research Council of Italy): I'm not completely agree because I mean biological tissue if you build a machine which is made by some biosomething you will have it which is biodegradable, which is good things. We will gonna have problems with you know garbage coming from electronics whatever. Well it's just a question of money if someone you know I mean if you someone will demonstrate that with the power of parallelism some biomachine will have the same you know teraflop power then they will just make it. I mean it's not the question. What I'm saying is that the added value will be that probably will have less garbage, you know.

Mirela Alistar (Hasso Plattner Institute): well, don't underestimate the computational power in an organism, because it's insane the machine that's going, the cellular machine is highly computational. It optimizes for everything, the way proteins would work and I'm going to give it to Sheryah as maybe he can help you more because he has a biochemical background.

Shreyas Shah [Nokia Bells Labs, New Jersey, US]: So I understand your perspective because biologically computing I guess we haven't reached that state where it compares to computers in

this advancement but if you think of the brain alone right the computing power of the brain that's all cellular organic and yet the like memory for example right where you're building memory into 32 GB 64 GB you have memory from years back somehow logic that we haven't unlocked how that's done but there's possibility to unlock that. I mean in the current state it doesn't seem like that and I can see your point and putting in something that is biological but there is a counter argument

Eduard Alarcon [UPC]: I ask the question to all panellists related to your comments and your reactions I think that you started in a sense bottom-up in terms of computational power and metrics is it faster is lower consumption we can state that but can we flip the question and talk about top-down system attributes with those systems, if they are more reliable, resilient versatile/adaptive, etc. not the way they are structured but their performance attributes at system level.

Filippo Castiglione (National Research Council of Italy): my idea is, I mean a biological system is not deterministic so we are now used to handle computation in terms of reliability yeah you have any well presentation you know my presentation was really along the line of what Sheryas. So I'm more interested see man coming from another community which is those of people making mathematical models of biological systems. So I'm more interested in the sensing equipment. So that's what I envision as you know the development of this community. What the industry will be for a community like yours? Because I think there is a big opportunity but anyway.

Moderator (Pietro Lio, Cambridge University): So if I remember you had some contact with me this recently it was a week yeah

Filippo Castiglione (National Research Council of Italy): I mean what I'm seeing is that there is a lot of interest. I mean up to now what is what is measurable it's somehow simply measurable. what I'm saying is that it will be great if in the future people will be able to measure in vivo things like obtaining let's say the immune system activity for some time I'm talking about measuring cytokines on the fly or counting cells in the blood and all this kind of things are now doable ex vivo or in vitro which takes time which is still okay. I don't know if you want to add something but there's a lot of work to do in terms of devices which are able to do these things and I think it comes from community like yours and community of you know a solid matter physics basically. I mean material science.

Moderator (Pietro Lio, Cambridge University): so, part of your research activity is modeling the signaling aspects of cells.

Filippo Castiglione (National Research Council of Italy): yeah, it's modeling the systems overall. So of course anything new which would come from this molecular modelling community will be good in terms of new ideas for models basically.

Moderator (Pietro Lio, Cambridge University): it would be good if now going on a molecular side. Probably Denis, can you introduce yourself and see if there is something about health and mobile it could be of interest.

Denis Manton (TSSG Waterford, Ireland): so my name is Denis Manton. I' m a research manager in TSSG worked alongside my four other colleagues in the room here Saasy, Daniel, Alan and Michael. So my background is very different everybody else on the panel. I have spent over ten years in the life sciences industry. I have a computer science background and fell into control systems engineering is the way I would describe have been involved in green field sites right up to commercialization of products. So I would have a very different perspective. I suppose on and how to stimulate industry engagement. so I think one of the things again I liked the analogy earlier as well where we're in 1985 and one of the other things that you have to take into consideration is the regulatory side of this and the compliance the FDA and understanding how to help industry overcome those types of issues because this is still widely well as you say there's growing interest in it. it's still very new for industry so there's a fear there and they don't know how to take it maybe to the next level and it is more along the lines of startups and spinouts from universities and institutes that are taking it a step further but I think being able to while you don't want to stifle the innovation at the experimental stage I think having that appreciation of compliance and regulation and at that level but that will help and build a good relationship with industry. Because they need to trust who people they're working with. Another way is maybe within your Institutes and universities to work with some of your colleagues who have traditionally worked with the like biopharmers if you're coming maybe from a more ICT side of it. They may already have those relationships built up and that's a big thing. because at the end of the day this is touching a patient so there is it's not about just changing a line of code or and building the next supercomputer or whatever it may be. There is a patient at the end of this and that brings an extra suppose responsibility to it. So from I suppose what the guys are talking about here and I can appreciate it but I think that on a very practical level there are a number of things that need to be taken into consideration from as you say we were talking about and mobile health earlier as well. you mentioned about HCI that's obviously hugely important and I think the interdisciplinary nature is well causes complications but it's required and if it does give obviously an extra complexity to it but I think as well there's a few things that can be brought in there from a very practical level that that will help stimulate further engagement.

Audience. Goksel Misirli [Univ Newcastle]: I'm a computer scientist and interested in computational design of biological systems, mainly synthetic biology. So my question is, is there any collaboration between industry? is there any work together to create a common roadmap, common vision for that researchers collectively? Or should we approach companies each individually?

Filippo Castiglione (National Research Council of Italy): I know that Europe had in terms of funding a huge track established in what was it FP6 the name was virtual physiological human which many of you probably know and that this track is still ongoing and FP7 actually starting at FP5 I don't remember and the people who are driving this effort are still you know they have a lot of energy. They funded an institute in England in Sheffield and they are pushing a lot to get in touch with industry. So they are involving them very much and they've opened the channel and they are getting feedbacks from the industry. So I see interest. That's the point. On the other hand, if we look at the huge you know pharmaceutical industry, I see some inertia to my idea coming from the fact that the vertices or those who take decisions are old people and they have no idea what we are doing here. So they are still in that kind of mentality in which the drugs are made by chemists and only that's my feeling and they move slow. That's why probably startups are the best. They go for this kind of technology.

Denis Manton (TSSG Waterford, Ireland): I think there's definitely an opportunity even for the people in this room and I've been talking to Alan and Michael and Sassi about this as well but there's opportunity to influence the next horizon 2020 the 2018 to 2020 work program. well that's probably a little bit late actually in that because they've already issued the draft and will be finalized in September but for the next year I think there is an opportunity to go to the Commission and start changing that mindset at that level which allows you then bring in these industry partners in a model maybe that they're familiar with as well. But and it's probably up to the likes of the people in this room to actually drive that and influencing of the Commission.

Emre Ozer (ARM, Cambridge, UK): I think the Commission should start a flagship program on synthetic biology and it's up to you guys. So we as a semiconductor company maybe or may not and UK is leaving the European Union in a couple of years on destiny less than two years so for the other European parts. That you should just push for it and that they should create. So they created quantum computing flagship program recently, graphene is there and human brain project. I think synthetic biology must be the next one and it's up to you guys.

Audience: so it's interesting. From the Bell Labs perspective, it's very academic in nature when it comes to research even though it's kind of like an academic lab in an industrial setting. So and I really mean that. Because when whenever from the management side when we when they're promoting a given projector direction the question of commercialization or you know what is the cost and what is the market for this it's actually negligible. Because that it's in a unique setting where we have a parent company with Nokia and there are things that are reached market which is a target so when it comes from an academic mindset to advance something the collaboration opportunities are much more lenient for us. so if there's so they even say like you know if there's a sensor that someone has either an academia or industry you know don't bother building it connect with them and take it the next step further and so that's the kind of mentality at least we have when it comes to this. And so over the last year we have talked with I personally have

talked with many different collaborators both academia and industry to see how it fits into this vision of an antenna network.

[Audience. Ryan Silva, Boston University]: I have to say who I am. I'm Ryan Silva. I'm really interested in design automation for microfluidics and I guess my question has sort of spins off of that. That seems like there's a gap where industry seems to be interested in doing their own research and academic setting if there is a capability developed that's paired with an application then one ought to expect a lot of startups being spun out. And really the only capabilities being developed for industry seem to be like being developed within that company rather than going out and saying hey we've got this cool idea for droplet based communications but we're looking for somebody to pick it up as a capability. Bottom line what I'm saying is it seems like you guys say that the hey there's a lot of opportunities to pick up capabilities developed in universities whereas the existence of all these startups being spun out of academics tells me that that's probably not the case in practice.

Audience: I think I have a slightly different comment or view and so it was about you know how to connect biology with electronics and whether this is going to be the next sort of revolution is going to happen. And I see that its goes hand in hand wherever that is useful to use biology and synthetic biology to design circuits and connecting that with electronic components the way that's going to go I guess. we see already companies like I have good contacts with companies like a medical device companies like Medtronic and GE and so forth and when I talk to them and they say that they believe in this type of work and they believe in that they call it as a bioelectronics you know the segment that they are building and actually they believe that the pharmaceutical companies will eventually will be collaborating in this area because most of the things that people can do with devices have been quite effective when it comes to human medicine. Of course you can argue that you know drugs have been there and you know they're effective and so forth. the investments done there actually takes much longer time and now there is a new interesting area coming up is called organ-on-chip. I think we didn't discuss so much here today because the lab on chip and everything organ-on-chip is actually as a very interesting area really trying to push the development and the testing of different drugs and we believe that within that organ-on-chip type of platform integrating electronic components so they're talking about nano-senses, nano-needles, all these things are going to be sort of integrated. So that we will be able to accelerate both the pharmaceutical industry and device industry in this area so I think It's going to be a very interesting period of time that we'll see a lot of interesting innovation coming out and also very happy to see that companies like ARM and also Bell Labs of course they come from very academic tradition looking into this and you know see some interesting opportunities and willing to in a work even you know traditionally we see that it's most of the innovations are coming from startup companies. Small companies and I also have some contacts in certain Stanford and also its companies there and for example Google actually has a big lab now working on this type of area.

So it's interesting that in a big companies also investing a lot of money and I don't know whether you guys want to make a comment on that.

Emre Ozer (ARM, Cambridge, UK): Microsoft as well, Microsoft in Cambridge they have a biological computer group recently formed.

Moderator (Pietro Lio, Cambridge University): yeah, okay, something quick from members of the panel and then we can hear somebody else.

Shreyas Shah [Nokia Bells Labs, New Jersey, US]: when you're saying with devices, you're kind of on chip so when you're talking Organ-on-chip and putting electronics you have one aspect of interfacing and then when you're talking on the body or inside the body there's a whole different. I feel an interface of control that comes in and what compliance and FDA come in so it's kind of two bins that are advancing.

Moderator (Pietro Lio, Cambridge University): so anybody else wants to say something about how to progress in the industry and progress in molecular communication via academia.

Mirela Alistar (Hasso Plattner Institute): I would like to introduce myself as well. so I'm Mirela Alistar and my expertise is in microfluidics namely droplet based microfluidics. I'm mostly my background is mostly academia and my contact with industry has been during my PhD. I've done an external stay at advanced liquid logics now acquired by Illumina the only company that released some commercial device using digital microfluidics for DNA sequencing and I've also had two startups coming from Academia.

Denis Manton (TSSG Waterford, Ireland): I just want to make another comment there when you're saying a lot of things that can be done. I think again I think was alluded to maybe through yourself earlier that what length of time and when it goes back to that where are we right now I think what's really helpful when you do engage with industry is to appreciate that they've got their or indeed pipelines they got their product pipelines and to be able to build on that is to you know to know the research you're doing is a three years or five years or ten years or 15 years out. You're going to have that in your head as well when you're talking to people to try and get their buy-in I suppose and try and so that they understand that you understand the pressures that they are under as well on their way.

[Audience. Tuna Tugcu, Bogazici university of Istanbul]: engineering is based on actual recursive research so you devote something you get some feedback and fix things and do up a new version and this is how it closed. The medicine world is quite different. They're quite slow because of the restrictions put by the regulations. So the engineering world and the medicine world are two separate worlds. As long as we don't find a way of fixing this you will not be able to catch the speed of innovations we had in computing, electrical engineering and communications. So I don't know how to do it. It's not easy because they have some logic in doing it that slow because it relates to people's lives but the times are changing so if somehow we can

contribute in maybe some other tracks of regulations for this kind of research it might help us to work faster otherwise we will have to slow down to their speed.

Denis Manton (TSSG Waterford, Ireland): I think that's a really valid point and there's a research group here in Ireland called the regulation software research group so they focus specifically on this. they are computer scientists by background but also registry specialists combined so they are working with the large Pharms and med device companies and other universities to try and help people be agile, keep moving fast, but at the same time they understand what the various medicine boards what the various compliance bodies are looking for and that's what we need is the kind of process around that to allow it's delivered so there are I suppose the number of leaders in that space that are doing its trying to linkup with them. I think is really important.

Filippo Castiglione (National Research Council of Italy): yeah, I totally agree. This is also happening in in this virtual physiological community modelling. they have established what is called a panel study called the in silicoclinical trial which is actually also track European funds which basically wants to demonstrate that people who do models are able to you know submit results which are in line with the results that clinician can submit or at least can help in this and in this process they have to establish contacts with you know those who really determine if a clinical trial can be accepted or not so that it's not just I mean there is a lot of bureaucracy behind, there's a lot of policy behind which requires efforts which scientists are not used to do but probably we should be also people to you know to make that step if we want to speedup things as just suggested.

Emre Ozer (ARM, Cambridge, UK): I mean that's a very important point vital point but it should not stop academics to do crazy research. I think they should still continue. You should not affect maybe a company is like we need to be you know we need to look into this you know. We need to speed this up you know In FDA what is this. You build something three years later you get the certification on but for researchers that this should not you should not worry about it. Some of you may be interested in this problem go work on it but some of the crazy disruptive ideas do it. Just don't make regulations stop you.

Mirela Alistar (Hasso Plattner Institute): I'm gonna address directly the questions. So I have a solution. It's controversial. So I' m trying to build around it a little bit. I think the regulations are there because of the way medicine is being applied which is not very centralized way. So somebody decides and takes a responsibility for someone else. if you take responsibility for yourself together with precision medicine with personalized drugs using the fact that we have all this advancements right now of knowledge and access to knowledge then it could work that these regulations won 't apply anymore. I mean it's legal in all the countries that I've been to take a photo of myself and put it online. It's illegal to do that to another person. So I cannot take a photo of you and put it online without your approval in many countries. The same way if I am the doctor and the way medicine is being used or applied is body me saying or you know having a

medication for a certain patient. what about enabling the patient s enabling each one of us giving us power to decide, giving us the tools, giving us the knowledge and enabling us to a certain point to make decisions for ourselves and then it's controversial how much the regulation applies and how much it does not but I truly believe that decentralization is a way to go as well.

Filippo Castiglione (National Research Council of Italy): I wanted to add that what you said basically this is already going on because if you're using you know the Fitbit to understand how much you want to walk no one will stop you on the other hand just to go in the direction what you said we don t want to substitute the doctor but we want to offer the doctor some other instruments. So it will still be him to decide what to do. Our job will be to make medical devices, monitoring devices which then you know converge the information to the doctor so I don't see much problem.

Audience: just a quick point on that though with the Fitbit and these medical devices one thing to keep in mind is a big issue is who does the data belong to who to start with and who does the the liability lie on. So when you talk about decentralizing and these aspects these are bigger questions which I guess might need more regulation when you try to get rid of what so just one thing.

Filippo Castiglione (National Research Council of Italy): This has to be part of the discussion in fact. I mean this this in silico-clinical trial committee is also brainstorming about this and it's speaking with you know regulatory agents. It's a reality.

Eduard Alarcon [UPC]: just trying to close this. I wasn't planning to contribute but at least tomorrow we should perhaps go from regulations into ethical implications of this work and at least tomorrow in the roadmap panel we will be working in and we'll talk about the ethical implications. But I'm a million ignorant on implications of this. I wanted to try to build a bridge between academia and Industry and I might be a bit controversial but hopefully constructively and I plan to share with you what we are doing with both IEEE but also with the Commission in Brussels. Because there's this problem we are facing is not unique to us to this community. So probably it's not just a point-to-point bridge but it's a probably a mesh to the bridge in it. Perhaps being summarizing or simplifying the situation in academia, individual researchers and research groups indeed as Emre you were saying we mainly work in a given discipline or a given discipline or a topic or in a given enabling technology. In different groups we will keep working into the separate topics because it's in the overlap of two close that adjacent disciplines that new emergent knowledge appears. We will keep working on that. might be that some companies large companies would like to take some of this new knowledge or technologies but I do think that very large institutions including large companies which are research oriented do need to address applications if you are very much market driven but else you can you are driven by vertical systems eventually grand challenges, humanity grand challenges we wish. All of them which seem very diverse, whether there are IT or they are into any other areas are always multidisciplinary.

They're always complex systems that are based combining different subsystems or different key enabling technologies and the like. So that's the matrix like structure I would suggest to consider. Academia mainly generating new knowledge into disciplinary and then companies collecting all this new knowledge and activity aligned to this verticals or applications.

Moderator (Pietro Lio, Cambridge University):: we have five minutes and then we have to move somewhere else to continue.

Shreyas Shah [Nokia Bells Labs, New Jersey, US]: so I like how you brought that up with bringing a connection between academia and Industry and I'm not sure if you're alluding to this when you said the big challenge. actually that's what came to mind before you said this and so we have like a Bell Labs challenge so anyone could apply and mostly in the academic groups apply and the idea is that they're to come up with basically innovative solution and now it doesn't have to be in a particular field like right now there's applications that are coming from synthetic biology from electrical from a design perspective and what happens is that they're paired with groups within Bell Labs and then what happens over the next months were selected they go through a process where they work together and now there's no market there's no commercialization result of that on the table. It's just a matter of taking an idea and seeing by putting like minds or even different minds on it as it goes along connecting more people and seeing what can we come up with and you know as a reward for the other who ever came up with the idea there's some prize award from their side but this idea of having a challenge and kind of stimulating. I think it's something that's picking up and there's even a mammogram thing we've there's someone who came from Apple who said that they put out challenges through sage bionetworks so for example detect cancer on a mammogram using machine learning. how can you best detect it and then that brings together teams and once those teams come together they could pair up at later stages in the challenge and so this is I mean it's not a one final solution but it's a means to bridge

Filippo Castiglione (National Research Council of Italy): may I ask you something. I mean what will be in, you know in a ten seconds sentence, your idea of involving people. What would you do if you have if you had the magic hand? What will be your approach? Wait an email, go and ring them, putting a blog on the Internet. I mean how can take anything from

Eduard Alarcon [UPC]: sitting in the same room to start.

Filippo Castiglione (National Research Council of Italy): but would you have, would you like to have a solved problem of or you want to tell look this is the way I would like to solve the problem. Give me the money. It's a complete different approach because I mean if you are a start-up you basically reach a point in which you have the solution and then they will you know buy basically but if I mean we are still I mean we don't have a problem which is solved. We probably need money. So but I mean big company they don't really respond to this kind of you know. That's the problem. So I think we should make an extra effort for that and solve the problem.

Shreyas Shah [Nokia Bells Labs, New Jersey, US]: maybe there's a mediator between industry and academia. There are companies I think they're in the U.S. I mentioned once SAGE bionetworks. We just met the person who started that last week and they're trying to connect both clinical academic and industry through different approaches and so for example they had one thing from computer science or algorithm point of view. There might be people out there that have an approach or a way to solve something but they don't have data. But if they had the data so what can they do with this? So those proposals where they put forth okay we have this, this way to do it but we need this particular type of data so then they submit it to this mediator company who will go through the proposals and see okay you know this is worth it and then they'll connect them that with let's say some clinic who has that data. So that is a paradigm which is coming up.

Annex 2: supporting material from working group


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SAMPLE
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TAMPERE UNIVERSITY OF TECHNOLOGY
European
Commission
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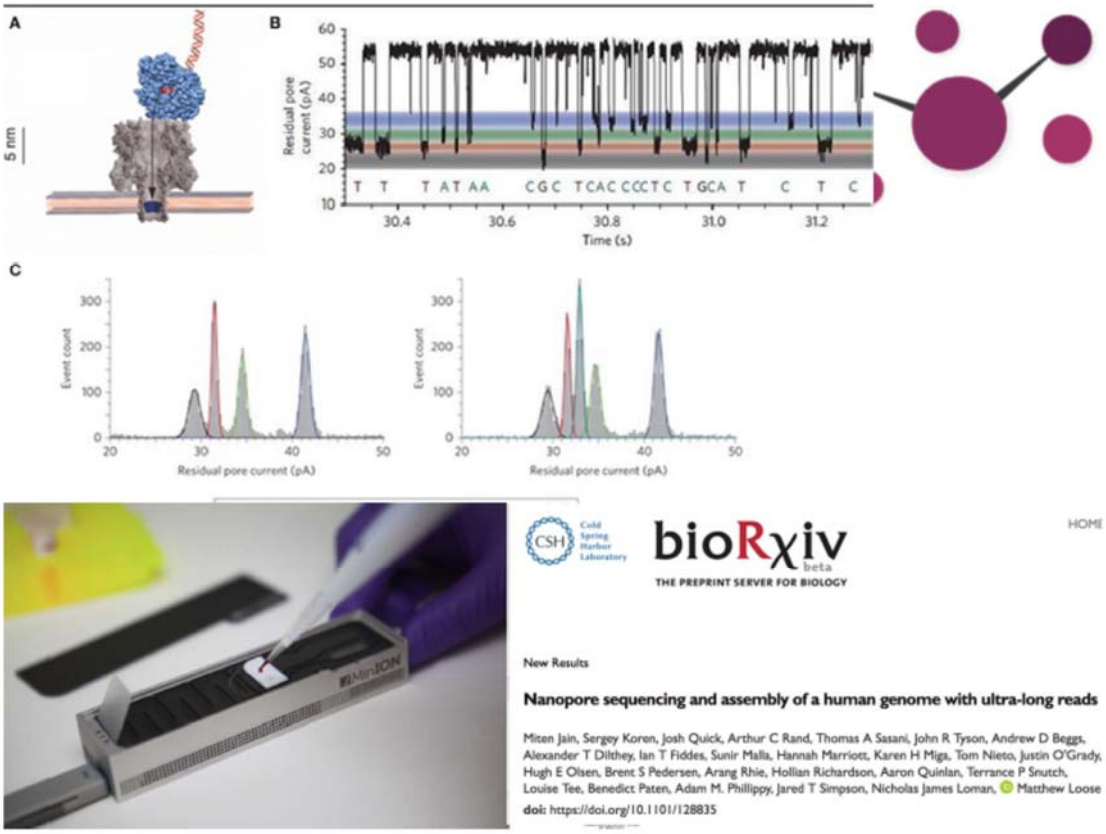
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doi: https://doi.org/10.1101/128835


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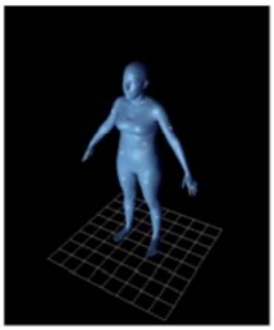

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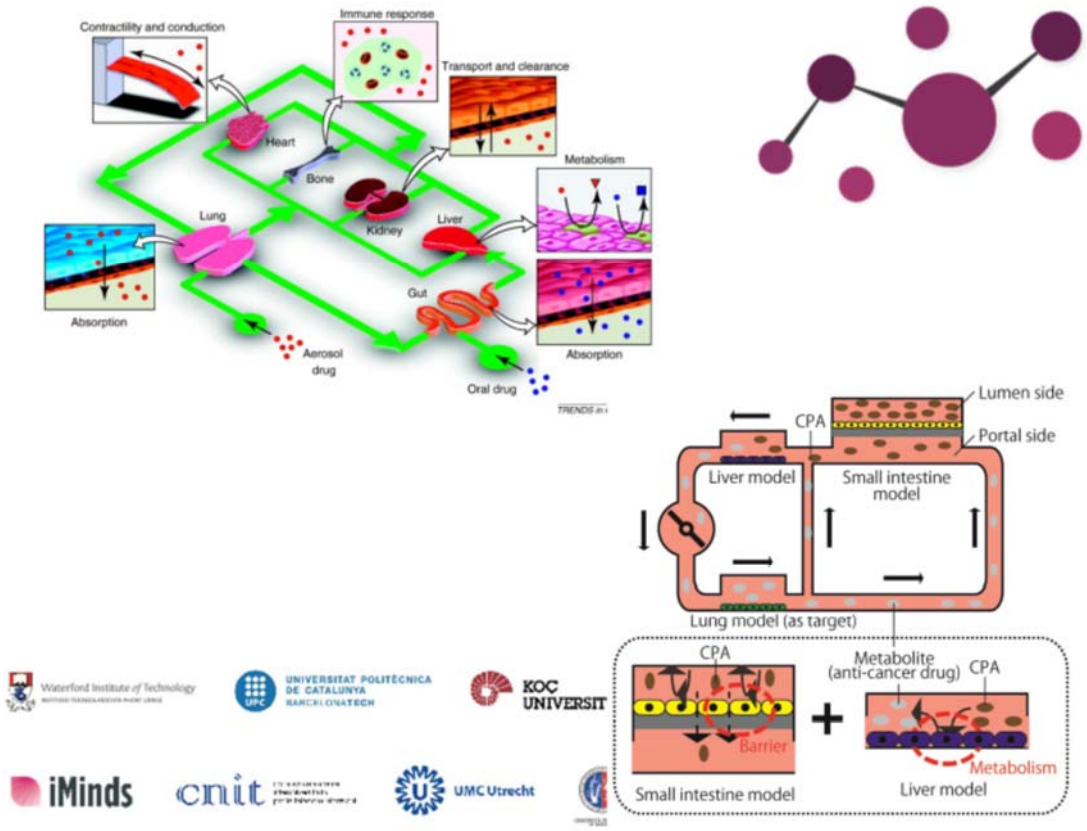
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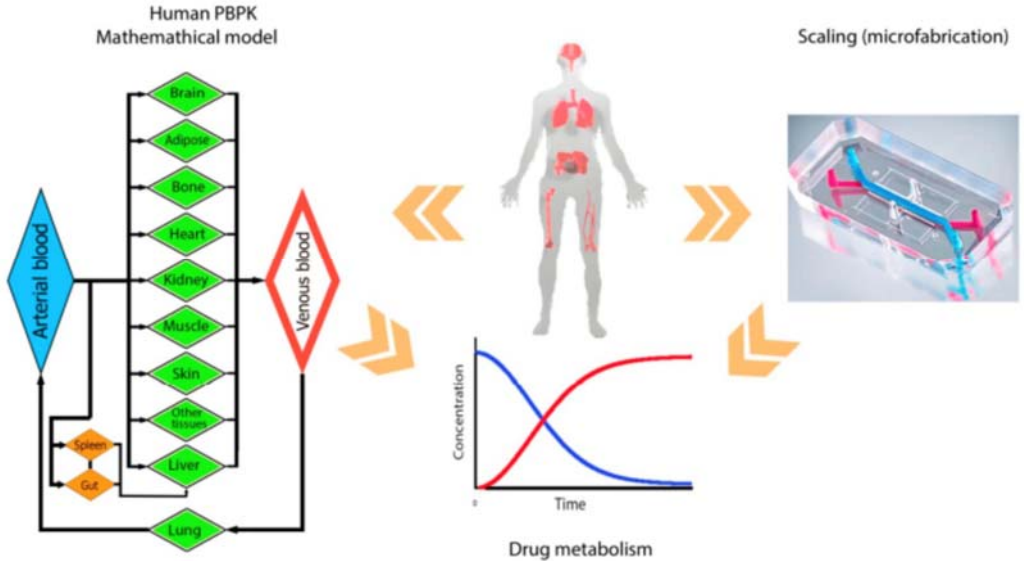

The design of multi-organ-on-chip platforms and the analysis of biological systems relying on th ephysiologically-based pharmacokinetic (PBPK) simulation. The drug action is recorded and us ed for the simulation process.

CHALLENGES

- Challenge 1: Molecular communication, what are the medical, environmental and personal devices more appealing for industry?
  - intelligent stents in blood
  - brain and nervous system technologies
  - immune system and inflammatory monitoring
- Challenge 2: How industry could start a market in molecular communication by leveraging on results from synthetic biology, systems medicine and cyberphysical systems?
  - Medicine
  - Synthetic biology
  - cyberphysical systems
- Challenges 3: Microfluidic technologies for inbody and extra body

Waterford Institute of Technology · Universitat Politècnica de Catalunya Barcelonatech · Koç University · University of Cambridge · Tampereen teknillinen yliopisto Tampere University of Technology

iMinds · cnit · UMC Utrecht · European Commission · Horizon 2020 European Union funding for Research & Innovation

November 7, 2016


Stimulating Industry Engagement in Molecular Communications
Dear Dr. Pietro Lio,
I'm Dr Lydie Jeux and I'm in charge of collaborative research projects for Elvesys Microfluidic Innovation Center (http://elveflow.us15.list-manage2.com/track/click?u=3260cb84c871a12da2a1c9e60&id=fccfa79d84&e=6a1ba562b7)
.
As you may know, besides developing microfluidic instruments, our R&D team is currently involved in several Europe funded collaborative research projects (http://elveflow.us15.list-manage.com/track/click?u=3260cb84c871a12da2a1c9e60&id=15a40dec18&e=6a1ba562b7) related to microfluidics (ITN, RISE, NMBP…). Our aim is to bring our expertise as a partner to new consortia.
Thus, if you plan to apply to a collaborative funding and are looking for a microfluidics R&D company for your consortium, I would be glad to assess with you the possibility of a research collaboration.Feel free to get back to me if you have any questions.
Kind regards,
Lydie JEUX, PhD
Head of collaborative research projects for Elvesys.
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