Model Based Control and Open Innovation 2.0

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Introduction

Mijnheer de Rector Magnificus, leden van het College van Bestuur van de Technische Universiteit Eindhoven, beste collega’s, beste familie en vrienden, zeer gewaardeerde toehoorders,

I am very pleased to find you all interested in listening to my valedictory lecture. I can imagine that many of you don’t see a direct relationship between ‘Model Based Control’ and ‘Open Innovation 2.0’. Both ‘Model Based Control’ and ‘Open Innovation 2.0’ strive to achieve well-defined objectives for a complex dynamic (sub)system within imposed constraints by making the most effective use of the dynamics of the system. I hope to clarify this relationship to you through my lecture. When I held my inaugural lecture on 8 June 1990, after having being appointed as a part-time professor in the field of ‘System Identification and Control of Industrial Processes’ at this university on 1 February 1990, I was – as a person who was intrigued by technology and its opportunities – completely focused on the challenges we faced in this field of expertise. Through my growing experience in working both in industry and in the academic world, I learned that the technology and engineering solutions we develop to solve complex technological problems can also be applied directly to solving complex challenges that we face in society on a daily basis. I also learned the importance of people and good, trust-based relations between people in order to make things really happen.

In this lecture, I want to share my experiences with you by highlighting some of the essentials I have learned from the wide range of activities I did.

In my lecture, I will tackle the following topics:
• Properties of dynamic systems that are most difficult to control
• Driving complex dynamic systems to desired conditions
• Difficulties faced in changing the equilibrium of a complex non-linear dynamic system
• Analysis of the main properties of a system in order to enable the synthesis of a system with desired behavior
• Earth as a complex dynamic system with society as a subsystem
• Solving major societal challenges faced
• An Open Innovation Ecosystem for Integrated Photonic Circuits and Systems market
Properties of dynamic systems that are most difficult to control

Before getting into a discussion of dynamic systems that are most difficult to control and explaining why, let me first start by explaining some basic concepts for people who are not familiar with system dynamics or people that may need some refreshment of their knowledge.

I realize myself that not everybody attending this lecture is a control systems expert. Many of the people present today don’t have an engineering background. For that reason, I will not use the standard tool of engineers: mathematics. Instead, I will try to clarify essentials using simple, intuitive examples. Let me start with a short explanation of dynamic system behavior and basic difficulties encountered in controlling these dynamics.
power available for making the transition and the system can handle the enormous power peaks during the transition without encountering a defect. Compare this to the heating of seawater by the sun versus the heating of your local swimming pool by this same sun: the water in your swimming pool will achieve a comfortable temperature much faster after wintertime than seawater does. In this case, the difference in the dynamic response is caused by the difference in the mass of water that needs to be heated with the same power per square meter applied.

Each system has such dynamic response characteristics. Simple systems like a room temperature control system show relatively simple response dynamics, whereas complex systems like a chemical plant or even your car, Blu-ray DVD player or printer may show more complex dynamic responses. The complexity of a system essentially relates to the number of basic dynamic elements that together form the total system, like separately-moving masses or springs, various heat capacities, capacitors or inductors in electrical or electronic systems. Each of these elements can be seen as a separate location that can temporarily store and release energy.

Control is a discipline that tries to design control systems in order to create a dynamic system that consists of a complex variety of interconnected energy storage elements that move from one condition to a new desired condition and realize dynamic transition behavior of a well-selected set of variables of this system in accordance with preferred transition tracks. The control system does this through the manipulation of a selected set of input variables of the system on the basis of the measured response of the variables of the system which need to be controlled. In the above example of room temperature control, the variable manipulated is the burner of the central heating system and the controlled variable is the measured room temperature. The burner is automatically switched ‘on’ and ‘off’ by the control system in order to achieve and maintain the desired room temperature. As a control system manipulates a selected set of ‘Input Variables’ based on ‘Measured Control Variables’, it will be clear that the control system does not change the inherent physics and related natural dynamic behavior of the system itself. It just drives the dynamics of the system to make the system behave as close as possible to desired behavior.

Transition dynamics become difficult to control when the system involves dynamics that oppose each other. The simplest system showing this kind of behavior is a system with two parallel paths (Fig. 2) from the manipulated variable (Fig. 2 and Fig. 3 Step signal applied) to the controlled variable (Fig. 2 and Fig. 6 Output response): the first path drives the controlled variable to a negative output following dynamic response path A (Fig. 4 Response of subsystem H1 to a step input), whereas the second path drives the controlled variable to a positive output with a slightly larger gain and a slower dynamic response following dynamic response path B (Fig. 5 Response of subsystem H2 to a step input). The ultimate response of this system is the sum of both responses (Fig. 6 Resulting output response of the system with counteracting dynamics).
This so-called non-minimum phase response makes it basically impossible to directly drive the system to a desired condition smoothly. Whatever we do, the system will first move in a direction opposite to the ultimate response. You can easily imagine the difficulty involved: pretend that the response of your car to the manipulation of your steering wheel shows this kind of dynamic behavior. In that case, the car would start making a right turn when you turn the steering wheel for a left turn. After moving some time in the wrong direction, the car would ultimately move in the desired direction and make the left turn. An example of a system that may show this kind of dynamic behavior is a distillation column used for the separation of liquids with different boiling points: vapor flow and liquid flow in the column are counteracting parallel dynamic processes. They have opposite effects on the ultimate system response, with vapor flow being faster than liquid flow. This may cause severe non-minimum phase behavior depending on the design of the column.

We have learned how to control these systems, but the controlled system response obtained always remains a compromise, as you can imagine (cf. Fig. 7 Typical compromised response of the controlled non-minimum phase system). A control system cannot change the natural dynamic behavior of the system, it can only excite the natural system dynamics in such a way that the desired responses are approximated as close as possible. By proper manipulation of the selected input variables, it can simply try to suppress undesired parts of this natural behavior of the system and use the desired dynamic modes extensively to make it respond closely to the preferred mode of operation. Comparing the time scales of Fig. 6
and Fig. 7 clearly shows that the controlled system in this simple example takes a lot more time to settle than the original system does and that it still has that highly undesired response of moving in the wrong direction first!
The real lesson to be learned here is that it is always better for systems showing such undesired properties to consider a redesigning of the system, if possible (cf. Fig. 8, Fig. 9). Otherwise, the response will remain a compromise. To get to best performing systems, co-design of the system and its control system is by far the best approach.

Figure 7. Typical compromised controlled system response of the non-minimum phase system

Figure 8. Re-engineered system with counteracting responses

Figure 9. Closed loop response of the re-engineered system
Driving complex dynamic systems to desired conditions

Without getting into the details, we just discussed the difficulties encountered in making complex systems behave in accordance with optimum desired behavior in real-life practice. In model-based control, we learned that not all dynamic properties of the system are equally important. Like in real life, some of the dynamics are more influential than others. To design properly-functioning control systems, we need to focus on the most influential dynamic properties of the system. To design robustly-performing controllers, it is sufficient to just make a model of the system that covers the most dominant dynamics and ignores the less relevant dynamics as we will discuss later. This approximate model is subsequently used for the design of the controller. Depending on the desired controlled system performance and robustness against unknown system characteristics, the controller is designed – in the frequency domain – as a stable approximation of the inverse of the model, with a smoothing filter tuned for the right balance of performance and robustness. An integrator in the closed loop ensures that the controlled system always ultimately achieves the desired point of operation.

Difficulties faced in changing the equilibrium of a complex non-linear dynamic system

In general, all natural systems are non-linear. Most of the time, these non-linear systems can be operated in many different stationary operating points. Often, we have a strong preference for a specific operating point of the system that meets highly-desired conditions, such as the realization of specific product properties (e.g. the processing of chemicals, steel, glass, food, etc.), minimum energy consumption, best conversion efficiency, preferred dynamic responses, minimum undesired side-products, etc. These optima can be stable or meta-stable. Driving a non-linear dynamic system from one stable equilibrium state to a different equilibrium state often turns out to be difficult. The reason is that you need very severe excitations of the system to move it away from the current equilibrium and make the system settle at the new, preferred equilibrium. Fig. 10 is an example of such a system with several stable and meta-stable equilibrium points.
In order to bring the red ball from the indicated stable equilibrium to the lowest possible stable equilibrium, a huge force is needed. Only after bringing the system across these maxima may it settle in the optimum stable equilibrium. In addition, sufficient energy needs to be taken from the ball to assure that it will settle at the absolute minimum stable equilibrium point and not move to another (less optimal) equilibrium. Typically, you need a large excitation to drive a system away from its stable equilibrium. Of course, the system will move out of its equilibrium through small excitations, but after stopping the excitation, the system will automatically return to its original stable equilibrium state, if the excitation is not large enough to get across the hill.

Trying to keep the system in a meta-stable equilibrium is even worse: it requires continuous efforts to bring the system back to the desired state even after a very small deviation from the equilibrium, as the system will automatically move to a stable stationary operating point if it is not driven back to the desired meta-stable state.

As I indicated earlier, real-life systems generally consist of various interacting subsystems. Each of these subsystems has its specific dynamics. The overall system behavior is determined by the ultimate behavior of these interacting systems. As you can easily imagine, not all of the dynamics contribute equally to the behavior observed. The actual behavior is determined by the dominance of specific subsystems and by the extent to which these dynamics are excited by external forces.

The dominance of a specific subsystem relates to the transfer gain of this subsystem between (one of) the selected manipulated variable(s) and the selected controlled variable(s) of the system. The extent to which these dynamics are excited depends on the manipulations applied to the system. Let me try to clarify this with another simple example.

Fig. 11 is an example of a complex system consisting of four interacting dynamic subsystems. The step response of this complex system is shown in Fig. 12. A good approximation of this complex system is shown in Fig. 13. Fig. 14 shows the step response of this approximate system. Both system responses closely resemble one another, as can be seen by comparing Fig. 12 and Fig. 14.
If the relatively simple approximate system is used to design the control system and this controller is applied to both the complex system and to its simple approximation, the controlled system performance of both will be very similar (Fig. 15). The simple approximation can therefore be applied well in the design of the control system. Following the design, this controller can generally be applied to the original complex system without significant degradation of performance.
Earth as a complex dynamic system with society as a subsystem

Let us apply the lessons learned from the simple control system examples to contribute to finding solutions for some of the major challenges we are facing at this moment. In the context of dynamics and control that we have just introduced, the total global ecosystem can be seen as an extremely complex dynamic system consisting of all the ingredients discussed. It may be considered a system built from many interacting elements. These elements refer to people, organizations, human-operated processes and systems, biological subsystems of nature and its many processes and physical and chemical subsystems. Each of these elements has its specific dynamics. Some of these dynamics are very fast, such as a solar panel converting light to electrical power (microsecond timescale) and some are extremely slow, such as the change of climate related to the conversion of fossil fuel to heat and CO₂ (>100 year timescale) or the even slower effect of the recovery of the living ecosystem after a major meteoric impact (>100,000 year timescale).

Our society can also be seen as a subsystem in this total global ecosystem. The dominant time constant related to societal changes is directly related to generations (~20 years): each generation realizes changes to the state of society. All the elements of the global ecosystem are subsystems, with each element showing its own non-linear, time-varying dynamic behavior. Each element is generally a non-linear, time-varying system (cf. Fig. 10 Non-linear system) operated in a state that depends on the interaction of this subsystem with the other subsystems (cf. Fig. 11 Complex system). The global ecosystem is far more complex than the simple structure shown in Fig. 11 though. The ecosystem has an extreme number of stationary operating points. In a simplified way, it can be seen as the surface of a waterbed: when you push the surface at certain points, the total surface shape changes dynamically and ultimately settles with a specific resulting stationary shape.

Although the global ecosystem is an extremely complex dynamic system, specific subsystems can be controlled, as discussed above. For the selected subsystem, preferred stationary operating conditions can be specified and, by means of an approximate model, a control system can be designed to make the subsystem meet the specified conditions, including transition dynamics. We need to be aware though that each change to the equilibrium conditions of the subsystem has an impact on the overall state of the total global ecosystem. Manipulation of the subsystem needs to be done with care to assure that the impact of the changes to subsystem conditions don’t disturb the overall global ecosystem equilibrium too much.
Solving major societal challenges faced

Over the past century, we have not only seen a massive growth in the world’s population from approximately 1.65 billion people in 1900 to 7.6 billion people at this moment, but also an even faster growth of energy use and consumption of scarce resources. Besides the significant growth of the world population, technology developments have enabled many people today to live at a much higher quality of life and welfare standards. These changes have huge impacts on energy consumption, the demand for good-quality food, the availability of clean drinking water for all these people and the corresponding rapid exhaustion of scarce resources. Since 1900, the world population has grown by a factor of 4.6 but energy consumption in that same period has grown by a factor of 14. Even more important is that approximately 1 billion of the 1.65 billion people in 1900 were living in extreme poverty. In 2015, the United Nations estimated that approximately 734 million people of the total world population were living in extreme poverty (Fig. 16 Number of people living in extreme poverty as a function of time). This major drop in the relative number of people living in extreme poverty is (in particular) the result of economic developments in Asia (foremost China and India). This drop in extreme poverty can also be seen as more people reaching minimum acceptable standards of living. This growing community of people also needs energy and other resources related to the increase in quality of life. This development, in which a larger part of the world population is consuming available resources, means that we have been at a very interesting point in history since 1970: for the first time, we can see that our established way of living implies that our consumption exceeds the resources available on earth. Fig. 17 shows in which month of the year we start depleting available resources each year. It is very clear that we need to act urgently to at least re-establish the balance. The effects of this massive consumption of our limited resources and the impact that this rapid consumption has on the earth’s ecosystem need to be reversed. A large
community (the Millennium Project\(^1\)) has recognized this problem and is mobilizing an ever-growing community to take this seriously and to work on solutions. They formulated the 15 global challenges we are facing and need to resolve (Fig. 18 Source: http://www.millennium-project.org/projects/challenges/).

It is clear that we need to change our way of working and living and must do so in a global setting. Society has to strive for changes that re-establish the earth’s ecosystem at conditions that enable ‘good quality of life’ living conditions for everyone forever. The turnaround needs to be established this century to ensure that the earth’s ecosystem does not change its equilibrium conditions to a state that destroys current life on earth (cf. Fig. 10 Moving the non-linear system to a new stationary equilibrium). Climate change is already well on its way towards moving us to a new equilibrium at which current life cannot survive, as long as we don’t reduce the consumption of fossil fuels and preferably restore conditions to the state of the early nineteenth century. This can be seen as a complex control problem acting on some of the most sensitive non-linear dynamic processes within the earth’s total ecosystem. Open Innovation seems to be a good way forward in order to develop the necessary applications and to establish the societal changes required.

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\(^1\) The Millennium Project is a global participatory think tank established in 1996 under the American Council for the United Nations University. It became independent in 2009 and has grown to 63 Nodes around the world.

Open Innovation Ecosystem for the Integrated Photonic Circuits and Systems market

Before elaborating on lessons learned from modelling and control to re-establish the earth’s ecosystem equilibrium, let me first discuss the very interesting field of integrated photonics and its Open Innovation ecosystem development as intermezzo.

Let me start with a short introduction. Integrated photonics is a domain comparable to microelectronics. At its core is the design and manufacturing of Photonic Integrated Circuits (Fig. 19 Example of a photonic integrated system), which are basic functional building blocks in integrated photonic-microelectronic systems. These integrated photonic-microelectronic systems are like microelectronic system enablers for the creation of scalable solutions to the challenges society is facing today. Similar to the impact that microelectronic systems developments have had on society, integrated photonic-microelectronic system developments will also enable major societal changes. They support the development of affordable and (on a global scale) applicable systems for things like preventive healthcare and healthy aging for everyone, well-managed energy supply from sustainable resources only, the complete recycling of materials, the tight monitoring and control of food, water and air quality, autonomous transport systems, etc. Like microelectronics, integrated photonics will show fast exponential growth.
growth in complexity. The growth factor in this increase in complexity will be 1.7/year, compared to a growth factor of 1.4/year realized in microelectronics during the past 60 years (Moore’s Law). Whereas size reduction has been the paradigm to realize Moore’s Law in microelectronics, the paradigm driving the increase in the complexity of photonic integrated circuits is parallelism.

Microelectronics has been one of the fastest developing industries. Since approximately 1980, Open Innovation – close collaboration in R&D between independent companies and knowledge institutes – has been a very important enabler for the pace of development. A global roadmap (International Technology Roadmap for Semiconductors – ITRS), developed and maintained by leading industrial parties and knowledge institutes, has been used as guidance for the required R&D. ITRS drives developments within institutes and companies in order to make sure that all technology, equipment and operations are ready at the time that the production of next-generation products starts. Essential aspects needed for the Open Innovation model to be successful are:

- A jointly-developed and widely-supported application-based technology roadmap as an R&D guide;
- Trust-based collaboration between the various industrial partners and knowledge institutes (team members);
- Coverage of all fields which together enable the timely development of solutions for all problems faced in realizing subsequent product generations;
- Making sure that every partner knows the strengths and weaknesses of one another to ensure that every partner is challenged to contribute on the basis of strengths;
- Ensuring that all partners benefit from the collaboration;
- All partners helping to solve the problems faced to the extent that they can;
- Applying collaboration agreements that support the timely release of next generations of technology and products.

A globally successful Open Innovation ecosystem can be compared to a world-class sport team:

- The team has one common goal: win each and every game they play;
- Each individual has specific knowledge and skills which are essential to the success of the team;
- Each team player fully trusts and respects her/his other team members;
- Each team member knows the strengths and weaknesses of every team member;
- Team members know how to best use the strengths of one another and do so;
- The team operates as a fast-responding, well-controlled machine;
- Each team member contributes to solving problems faced or caused by mistakes made;
- Mistakes are used to learn from and not to blame the individual that made the mistake;
- Every team member gets its share in successes.

The Integrated Photonics Circuits and Systems ecosystem - PhotonDelta - is developing along the Open Innovation characteristics outlined above. However, the high growth rate of 1.7/year, together with the global scale and limited available experts, is putting additional requirements on the ecosystem. The 1.7/year growth rate means that a next-generation technology needs to be delivered roughly every 1.3 years, with twice the functionality of the latest generation for about the same cost and the same chip surface. Speed of development will therefore be the major driver for success. Mechanisms that slow down developments are no longer acceptable. Discussions on financing of activities and the related IP ownership are a major obstacle in current Open Innovation collaborations today and largely determine the speed with which results ultimately become available to the market. This is putting a lot of pressure on IP protection and licensing. Solid IP mechanisms need to be established and agreed amongst partners upfront in order to maximize the speed of development. This is an important point of attention in Open Innovation 2.0. The rapid ramp up to large global demand implies that all solutions created have to be scalable to mass production. The limited number of experts available, in combination with the challenges to be resolved, requires solid teamwork, parallel research and the development of various alternatives in a global setting in order to ensure that problems can be resolved in a timely manner. Scarce resources need to be used efficiently. A next generation of the Open Innovation collaboration concept is therefore needed to meet these requirements. The national plan Integrated Photonic Circuits and Systems and the foundation formed to realize the plan - PhotonDelta - are building up the Dutch Open Innovation ecosystem on Integrated Photonic Circuits and Systems. This ecosystem has to become one of the global hotspots in this field, both for R&D and for the manufacturing of equipment, products and applications.

2 Complexity: number of basic functions per unit of surface
Open Innovation: the importance of mutual trust in achieving goals and ambitions

Integrated Photonic Circuits and Systems are just one example of base technologies needed to create solutions to the major challenges we face. The societal problems to be solved are very complex and require contributions from many fields of expertise. Keeping in mind the dynamics and the large time constants of the underlying processes and interacting dynamic systems in particular, very little time is left to truly initiate the changes. We have to move towards operations of processes and systems which do not harm the earth’s ecosystem while offering ‘good quality of life’ conditions to every individual. Resources available for doing so are limited. It therefore makes a lot of sense to closely work together in an Open Innovation structure. By doing so, the best feasible results can be achieved in a relatively short time. In our Brainport region over the past decades, we have learned the strengths of such a network of intensively-collaborating partners. ASML, ProDrive, NXP, Philips, Thermo-Fisher Scientific, Paccar DAF and DSM are just a few examples of companies in our region that actively participate in and benefit from the Open Innovation collaboration between companies, knowledge institutes and the government. Holst and TNO-ESI are two nice examples of development centers in the region which bridge the gap between research and the industrial development of commercial successes. This collaboration, with exchanges of staff between companies and knowledge institutes during the last economic recession, is another nice example of how to exploit the strengths of collaborating partners. During this exchange, employees of companies were offered the opportunity to work with researchers on focused, long-term R&D topics relevant to their companies. Companies like ASML, Philips, NXP and many others benefited from this mechanism through the fact that they did not lose valuable employees due to the economic recession. After the recession, the employees came back to the organization with valuable new knowledge that they could immediately apply to the benefit of the organization. The contacts established between people during the exchange of staff further strengthened the process of collaboration between companies and knowledge institutes.

During economic highs, the same mechanism can be used in the opposite way: offering researchers the opportunity to have a sabbatical at the companies and learn about challenges the companies are facing. These mechanisms require full mutual trust and openness in order to achieve ambitious goals.

Looking into the future, collaborations are crucial to the solving of challenges faced and the further strengthening of the region. The strengths of this region in High-Tech Systems (next-generation mechatronics), Integrated Photonics, Personal Health Cure and Care, Automotive, (bio-)chemical processing, etc. form the basis for future success. The further extension and strengthening of the Open Innovation collaboration enables the cutting-edge development of technologies and their application to the major societal challenges faced. The control systems discussed earlier make it clear that it’s wise to avoid strong counteracting forces in the system, as these slow down the process of achieving targets (cf. Fig. 7 and Fig. 9, respectively).

To assure the best chances of success, each of the parties involved needs to contribute in accordance with their strengths and the roles that match with the kind of party that they are. The government, for example, has to focus on the long term (>10 years) and create conditions. Thoroughness, reliability and continuity in policy are keywords that are essential to the government and its operation. The government has to stimulate the ecosystem through the timely development of essential infrastructure, facilitate new initiatives and focus on performance by taking away potential roadblocks of the economic development of the ecosystem. Knowledge institutes have to contribute with solid, focused, long-term research targeting the timely creation of solutions for future challenges. They also have to participate in high- and medium-risk early stage joint developments and bring in appropriate expertise in order to minimize risk in developments. They need to be an expert partner in the development of prototypes and industrial demonstrators. They have to actively stimulate the mutual exchange of knowledge. They have to do both blue-sky research and research driven by business opportunities and challenges. Furthermore, knowledge institutes have to take care of both education programs for young people and lifelong learning programs for specialists. Industry and companies have to organize for commercial successes in a very competitive global market. They have to establish well-timed innovations in collaboration with other industrial partners, knowledge institutes and the government. They have a leading role in setting the agenda for future technology needs and application developments. They have to create new jobs and earn the capital needed for continuity in investments and the further expansion of the ecosystem.
All parties involved must avoid spending significant time on non-productive activities. Wasting precious time for accountability, establishing fierce upfront competition to chase funding and the disruption of continuity in R&D are just a few examples of activities that need to be minimized or, even better, avoided. Parties have to act as strong team players and must work together on the basis of mutual trust. Basic principles that govern strong collaboration amongst partners are: fully trusting and respecting one another, accepting that mistakes are made while working on projects, organizing the early detection of things going wrong together, working together to quickly resolve problems faced, organizing random checks to monitor quality, widely discussing problems faced and solutions created to jointly learn from difficulties encountered, celebrating successes and sharing the credit for it.

Societal Challenges: roadblocks and the potential impact of counteracting mechanisms

A roadblock frequently faced in the organization of activities is counteracting forces. Some examples are:

- Optimistic entrepreneurs and pessimistic investors together managing risks by defining tightly-specified milestones and go/no-go decisions with opposing concerns;
- Stubborn developers endlessly disputing the different ways to solve challenges and not noticing that objectives can be achieved in many different ways;
- Researchers claiming too wide a field of research while they only cover a small, specific part of the field and, in this way, blocking other researchers from also contributing;
- Health insurance companies and cure/caregivers disputing the cure/care provided and the accountability for the work done.

Each of these examples can be compared with the aforementioned hard-to-control non-minimum phase systems and the performance limitations imposed by the underlying opposing dynamics of the subsystems. The counteracting forces in the system significantly slow down developments without any advantage or need to do so. As we learned from control system analysis, the counteracting forces have to be made part of the system in a well-dosed setting in which counteraction is productive to keep things sharp without blocking fast realization of objectives (cf. Fig. 7 and 9). The counteracting forces may not be equally strong. Their impact on the ultimate system responses should differ sufficiently to enable fast responses and the rapid settling of the system. They need to be managed adequately in order to avoid the loss of fast response times to market opportunities and the appropriate anticipation of these.

The way that our society is organized today has many mechanisms that result in the significant loss of efficiency, such as using scarce expert resources in the wrong way and the resulting loss of reaction speed. Due to a lack of mutual trust and counteracting forces being part of the system, progress becomes sluggish. This is again the result of opposing mechanisms, which behave as the non-minimum
Polarization in society versus mutual respect and cooperation

Our current society is facing many challenges. Society is being confronted with a rapidly-growing number of dissatisfied people who no longer accept established order (e.g. ‘Yellow Vests’, fundamentalists, Hong Kong students). Pressure on established ways of working is becoming visible. Protest demonstrations and even violent actions by fundamentalists are organized to attract attention to this dissatisfaction and to try and enforce changes. The leaders elected today are another way that this pressure on the established societal mechanisms is becoming visible. Dissatisfied people vote for persons who are opposed to the established order and want to effect change. Examples are the outcomes of recent elections in the USA and the UK. Society is becoming polarized. The effect of this polarization is that it becomes far more difficult to make commonly-accepted decisions and to achieve intended results. Many people oppose decisions and make it hard to make progress and quickly solve problems. Trust and mutual respect are lost and, as a result, wide support and cooperation are lacking. A nice example of the resulting malfunctioning of the system due to polarization is the Brexit process in the UK. Democracy cannot handle a completely polarized society. Control becomes impossible due to almost equally strong opposing forces, similar to the non-minimum phase system with close to equal opposing subsystems. The lesson to be learned is that it is wise to create winning teams and trust within these teams. A winning team consists of experts that cover all the skills and expertise needed to win the game. The experts of the winning team respect one another, fully trust each other and have one common goal: winning the game together. What counts primarily is the overall result. Personal interests are subordinate to the common goal. Furthermore, the team members must not be annoyed by the requirement of detailed accounting for the work done. The results achieved by our Solar Team Eindhoven during the past four World Solar Challenges (2013, 2015, 2017, 2019) are a nice demonstration of the way good teams can be created and successes can be realized.
Open Innovation 2.0: the essentials

As indicated above, society urgently needs to solve major challenges faced. To do so, established mechanisms considered crucial to our current way of living need to be drastically changed in order to comply with sustainability constraints. We need to completely re-engineer, for example, our energy supply systems, our food supply, our transport systems, our healthcare and cure systems, our security systems, our city environments and their local ecosystems, our way of handling scarce materials and our waste handling and materials recycling systems, to mention just a few. In this case, re-engineering basically implies a complete re-thinking and redesign of the systems and the ways we operate them. In line with the complex system concept operation difficulties discussed, we need to move from current stationary equilibrium points to new equilibrium points of the most relevant subsystems, which together determine the equilibrium of the highly non-linear earth ecosystem. The critical subsystems, following redesign, have to be operated at equilibrium points that re-establish the subtle balances while simultaneously supporting ‘good quality of life’ conditions for the total world population in the coming millennia. Simply stated: the new conditions created need to ensure that the grandchildren of our grandchildren can live pleasant and enjoyable lives on an earth that flourishes and remains doing so.

The current consumption-based operation regimes have initiated a major transition in the balances of our earth’s complex ecosystem. At this moment, we are well on the way to settling at highly undesirable new equilibrium conditions. The simplified explanation of what is going on is that we have initiated a transition away from the equilibrium ideal for human life with a force that will be large enough to settle at a new equilibrium with conditions that ultimately result in the extinction of human life (cf. Fig. 10). Rapid action is therefore required. The earth’s ecosystem has to be driven back and settle at an equilibrium state which is close to ideal for human life. The best way to achieve this is in an Open Innovation 2.0 approach that supports such a huge operation as fast as possible in a robust way. In this case, robust implies a large chance of success within the imposed timeframe. Fast implies that we preferably need to return to the equilibrium at the start of the industrial revolution before hitting a point of no return, after which the non-linear system will automatically settle at a new, undesired equilibrium point. The Open Innovation approach is the setting in which a large group of expert teams all over the world comply with the following conditions:

- Securing the expertise and capacity needed;
- Jointly developing a roadmap that outlines the ambitions and R&D paths with alternative tracks for solving potential roadblocks;
- Trust-based collaborations between the government, industrial partners, knowledge institutes and representatives of communities;
- Covering all fields that together enable the timely development of solutions for all problems faced in achieving the milestones of the roadmap;
- Making sure that all members of every party in a team knows the strengths and weaknesses of all other parties to ensure that every partner contributes on the basis of its strengths;
- Ensuring that all partners benefit from the collaboration;
- Ensuring that all partners help to solve problems faced to the extent that they can and don’t blame each other when mistakes are made;
- Applying collaboration agreements that support the fastest possible development.

Open Innovation 2.0 adds two additional aspects to the earlier Open Innovation approaches: the speed of development is increased by removing mechanisms that slow down development (e.g. financing of the R&D needed, IP struggles) and the collaboration is not just restricted to regional partners.
Final word

This final word should also be the first: whatever we do, it’s all about people and the relationships between people. I want to thank all of the people that worked with me and helped me, the people that motivated and stimulated me, the people that approached me with marvelous ideas, the people that were willing to listen to me and discuss with me, the people that helped create opportunities and the people that criticized me. All were essential in everything I have been able to learn and realize.

I am one of the few people who has gotten the opportunity to meet many people in many countries and with many different cultural backgrounds. From these contacts, I learned the importance of carefully listening to people and understanding the underlying motivation of people to act in the way that they do. I have learned from this the importance of good relations based on mutual trust, respect and accepting that everybody is entitled to make mistakes. The collaborations based on these values are the only true candidates for success. As I have met and worked with so many people, I will surely forget to mention people here that should be included in my words of thanks and appreciation. If you find that your name is not mentioned where it should be, I thank you implicitly here and apologize for not referring to our collaboration, which I definitely enjoyed.

I want to give the first words of thanks to our current and previous Board members. Dear Hans, Amandus, Jo, Jan, Frank, Robert-Jan and Nicole, I want to thank you for the many pleasant and constructive discussions we had. In all of our discussions, we focused on the best interests of our university, region and society. We wanted our university to be an inspiring and challenging learning space for our students and staff. Looking at what we have achieved in the past 15 years, I am pleased to have been part of the team. I look at the results achieved together with pleasure and I hope you do as well. I also very much enjoyed the informal moments and events together. I look back on this time with very warm and pleasant feelings and memories. Thank you!

Dear colleague deans and former deans, I also want to thank you for the pleasant time we had together. Although pressure was high on each of us from time to time, we were always constructive in helping each other to solve the problems we faced. I always felt like a respected, trusted and appreciated member of a winning team.

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I hope you do as well. Together, we were able to guide our university through difficult times and make it stronger. I very much enjoyed the opportunity I got to work on this with all of you. Thank you!

Being responsible for the International Relations of our university gave me the opportunity to work and talk with many people inside our university and within our wide community of international contacts. I want to thank all of the people I could work together with to strengthen our relationships. In particular, I want to thank Laurent Nelissen and Lisette Appelo for the pleasant collaboration. I want to say a special word of thanks to Marleen van Heusden. Marleen, you have been the person who carefully prepared all meetings and meticulously organized all of our uncountable trips. Your preparations were instrumental to the achievement of the results we aimed for. Thank you for your support and hard work!

Dear IPI, UT and Photon Delta colleagues. For the past four years, we have been working very hard to further strengthen our excellent position in photonics research and development and helped build up strong industrial activities. I have deep respect for what we together as team – but especially you the scientists – have achieved. The excellent work you have done and are doing has enabled us to attract global attention and to become recognized as leaders of national, European and global Integrated Photonics Circuits and Systems developments covering the whole field, from fundamental materials research, device and circuits-related R&D to integrated photonic-electronic system R&D. Thank you very much for this and especially for the very pleasant and constructive way we worked together! The hard work we have done in the past years is going to pay off in the coming years. The strong ecosystem is getting up to speed. This ecosystem will help to further strengthen our R&D infrastructure and activities and to attract and educate many bright young people to become future experts in this very promising and beautiful field of technology.

Dear staff members of our EE department. As dean, I very much enjoyed working together with all of you. Working with such a team of marvelous people is what everybody wishes for. Although it has been hard work, it never felt like a burden. I enjoyed each and every day I could work together with you. Together, we have been able to make our department shine. I very much liked our meetings, the precious moments we had together and also the massive support from you during the difficult moments we had especially when we lost a colleague. Thank you very much for our many precious years together!
Dear members of our CS group. With the many tasks I had over the past decade, I hardly had time for the field I like so much: System Identification and Model-Based Control. I enjoyed the very limited time I could spend discussing research challenges faced, meeting with our students, preparing and having our project progress meetings, discussing new project opportunities and working out proposal details even further. Since my appointment as part-time professor in February 1990 and even during the many years before this, I always enjoyed the in-depth discussions we had while working together with the group. In this respect, I especially want to thank Ad Damen, Ad van den Boom, Pieter Eykhoff, Paul van den Bosch, Paul van den Hof, Leyla Ozkan and Jobert Ludlage. It has been a privilege and a pleasure to work with you!

When I mention the nice and warm remembrances of the many things we did in the field of model-based control, I also must not forget to mention the many pleasant meetings and activities together with Okko Bosgra and Wolfgang Marquardt. I always will remember our meetings and the many meetings with our colleagues in academia and industry with joy. Closely related to the control work was the work on the ‘Chemical Transistor’, the ambition to enable much tighter control of chemical processes. I especially want to thank Willy Ahout, Ewit Roos, Hans Niemantsverdriet and Cees Ronda for the many pleasant hours in which we discussed this topic and many others, dined together, had drinks together and also enjoyed good quality time with our partners. Dear friends, thank you very much for this great time together!

All the activities I have been doing have generated an awful lot of work to follow up in terms of delivering promised deliverables, reporting, organizing meetings, workshops and conferences, etc. I could never have done this in the way that I did without the support of a personal assistant who is proactive and only needs a few words to understand what need to be done. You have been the person in the back taking care of everything that was needed to make things happen. Yvonne, Greetje and Barbara, thank you so much for your patience with me and for being the office partners I always could rely upon!

I also want to say special thanks to the PhD students I could work so closely together with. Heinz Falkus, Jozef Mazak, Leon Ariaans, Jobert Ludlage, Arthur Nievengeld, Mario Balenovic, Rob Tousain, Mathieu Westerweele, Dennis van Hessem, Andre Tiagounov, Patricia Astrid, Leo Huisman, Joghem van den Berg, Maarten Nauta, Satyajit Wattamwar, Femke van Belzen, Mark Mutsaers, Jochem Vissers, Jasper Stolte, Quang Tran, Yibin Bu and Zhenghang Zhu, thank you very much for the nice times together and for the many discussions we had both on science and technology as well on all the other areas. It was a pleasure working with you.

As I mentioned already, I have been pretty busy with the wide range of activities I did. You can only spend so much time and energy for work when you are fully supported by your family members. I want to thank my children Peter and Brechtje, Nicole and Rob and Eric and Joliek and my grandchildren Siem, Nora, Fabian and Milou for respecting the fact that I frequently had to do some work when we could have been spending our time doing nice things together. We will have this quality time together from now on!

I have to say a very special ‘thank you’ to the love of my life. Lianne, without your endless patience with me and without your infinite support, I could never have done the things I did. I love you! We will definitely have far more quality time for doing things together with our children and our grandchildren. I look forward to many years of good time together and with our family!

Ik heb gezegd.
Curriculum Vitae

Prof.dr.ir. Ton Backx was appointed part-time professor of Control Systems at the Department of Electrical Engineering at Eindhoven University of Technology (TU/e) on February 1, 1990.

Over the past 42 years, Ton Backx has worked in both industry and at the university. He received his MSc in EE (cum laude) from Eindhoven University in 1977 and his PhD in 1987 as part of a joint Philips-TU/e research program while working at Philips. In 1990, he was appointed as a part-time professor at Eindhoven University of Technology, working in the field of modeling and model-based control of industrial processes. He accepted a full-time position at Eindhoven University of Technology in 2006, initially as Dean of the Department of Electrical Engineering (2006-2016). He was later appointed as Vice-Rector of Eindhoven University of Technology, responsible for strengthening collaboration between the university and industry (2010-2016). In 2016, he became Vice-President of International Relations. Since January 2016, Ton has been responsible for R&D on Photonic Integrated Circuits and Systems. He founded the Institute for Photonic Integration in April 2016. He also co-initiated Photon Delta, a collaborative ecosystem for research and exploitation on behalf of Photonic Integrated Circuits and Systems-related companies and R&D institutes.
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