27 April, 2000

Embedded Systems and the Future of Swedish IT-research

This document argues for the importance of research into *embedded systems*, and outlines a possible continuation after 2002 for the national embedded systems oriented research programme ARTES.

Summary

A major part of Swedish industry is manufacturing products with embedded computer systems. To stay competitive we need continued efforts strengthening the competence in designing such systems. In particular, since software is the critical factor dominating the design, we need a focussed effort into embedded systems software development. The ARTES research network has established an important basis for such an effort.

Embedded Systems

Embedded systems is the automation of products by a built in (embedded) computer system. Rather than focusing on the virtual realities of the *new economy*, embedded systems aims at developing and controlling real-world devices. Embedded systems come in many flavours, including micro-mechanical devices, vehicles, and larger industrial complexes. The majority of embedded systems are real-time systems, in that their correctness is depending on the timely response to stimuli.

The very predictable improvement in price/performance will make sure that the use of computers will continue to spread to new areas. They will appear in our home, in cars, in mobile personal assistants, in all kinds of process and production controls, in health care and not the least in telecom, multimedia and entertainment. The great majority of these computers will handle trivial tasks, but in rapidly growing number they will take on advanced and vital functions, which have to be handled in real time. Furthermore, many of them will be connected, either directly to the Internet or via appliance servers, and very often via wireless systems to avoid bulky cables.

It goes without saying that Swedish industry must master all aspects of these embedded systems to stay competitive and survive. It is not just Ericsson that considers real time software as a core business, but also ABB, the automotive industry with all its vendors (including many small and mid-size companies), and a rapidly growing part of our mechanical industry. Not to mention start ups working with reading pens, routers, mobile products etc. Distinguishing features in all products comes to a very large extent from real time software and their ability to communicate with other products.

Misconception 1

Misconception: All companies using IT in their production belong to the IT industry.

Today, essentially the entire Swedish industry is using IT in production of its services and goods, i.e., IT is used to support the main business. It is important to realise that this aspect of the use of IT in industry is not indicative of the term IT industry. Rather, the aspect that distinguishes IT industry is that IT itself is a core component in their products. For instance, ABB is an IT industry that may sell an Advant-system to Stora Enso. This does not make Stora Enso an IT company. The important difference is that whereas Advant is core business to ABB, it is support to the core business for Stora Enso. So while Stora Enso might survive with a process control system from say Siemens, ABB Automation Products would not exist today without its Advant product. Furthermore, it is important to realise that the dominating part of Swedish IT-industry (and a major part of Swedish industry) is producing embedded systems, including companies such as ABB, Atlas-Copco, Ericsson, Saab, Volvo, etc.

Misconception 2

Misconception: IT means Internet.

Many conceive IT as the ubiquitous use of Internet-technologies for surfing and providing net-services, such as e-Commerce and Internet-Banking. Though having an important impact, these services and other usage of desktop and related computers only amounts to a very small fraction of computers being used today. As a matter of fact, of the approximately 4.500 million processing units produced in 2000, only around 150 millions will be used in these "ordinary" computers; the remaining processors will be embedded in different types of products. These are the computers dealt with in Embedded Systems.

Misconception 3

Misconception: Microelectronics is the dominating aspect of embedded systems.

Embedded systems are frequently confused with microelectronics. For instance, SSF is in its strategy document from December 1999 stating: "*… currently microelectronics corresponds to 25% of the production value of a car. Microelectronics is the main factor determining the performance of many products. An increasing fraction of the added value of products is due to its microelectronic circuits. …*"

This is misleading, in that it indicates that the added value is due to the hardware circuitry. Facts are that, though providing an important enabling technology, the hardware related costs are typically only a small fraction of the total cost; the main costs are related to the software system. This is in many cases (including cars) also true when considering production costs, due to costs for software licenses. In most embedded systems, the hardware consists of standard electronic components available in large volumes at low cost, whereas the software to a large extent is specifically designed for the application at hand. For instance, for ABB's industrial robots the software constitutes more than 90% of the value of the computer system, since this is where the knowledge of the controlled process is embedded.

Challenges for Embedded Systems

The New World of pervasive computing, with millions of computers virtually everywhere, brings new opportunities but also new problems. On a system level, the most important challenges are how to develop and manage the software system, while guaranteeing sufficient quality at acceptable cost. These are issues that partly are addressed by ARTES (se enclosed folder), but which deserves an increased attention to match the problems encountered by industry.

The main problem (and strength) with software (compared to hardware) is its flexibility and that it is not governed by any natural laws, except timing. Traditionally, methods that for certain classes of systems can provide timing and reliability guarantees have been developed. These methods need to be extended and made more generally applicable.

Additionally, industry needs research into software and system architectures that can provide appropriate structure, flexibility and infrastructure, while making it possible to guarantee quality at reasonable cost. In several cases this will mean absolute timing and reliability guarantees at virtually no cost. Specific topics that should be addressed include:

- **Correct behaviour during the lifecycle**. The competitive pressure, together with growing functionality and complexity of embedded systems, means that such systems cannot be built from scratch each time. Instead, they have to be composed from existing building blocks, often emanating from different vendors. Not only that, as all software systems, they will be updated during their entire lifecycle. These are not PCs where an error causes irritation and often can be corrected with a restart, but systems where an error may have serious and sometimes catastrophic consequences. Research is needed on the dynamic architecture of such complex heterogeneous embedded software systems, as well as on the process on how to build and maintain them.

- **The updating process**. A growing problem, as the number of embedded computers per person increases, is the maintenance of software systems. There will even be many computers in our appliances that we will not be aware of (and do not want to be aware of), but which require updates and downloads of new software. In many cases the software must be updated "on the fly" while the system is running. This is done already today, but much remains to make these updates safe and cheap enough in many applications. The sheer volume, updating thousands or millions of computers, adds to the updating problem. The only feasible way to handle the volume is to do remote updates over interconnected networks, possible the Internet, from specialised management servers.

- **Safety, security and integrity**. Correct behaviour is the first condition to achieve safety, security and integrity. But special mechanisms are also needed. The need for safety in a car or a medical device is evident. In most of the embedded systems a huge amount of information will be handled, information to which there is a great number of "interested parties". The fight for better security, not the least to guard our integrity, will have to be fought constantly.

There are, off course, also important challenges on the microelectronics side, including how to minimise power consumption, weight and cost, together with robust integration of different technologies and with mechanical devices.

All the above and several additional technical issues are important to address. The most important challenge for Swedish industry is however to find qualified engineers for product development. Research/graduate education efforts into embedded systems will not only provide competence in this area, but also provide an increased focus on embedded systems in the entire educational system.

International Research Trends

Real-time systems is identified as one of the action lines within ``Key Action IV: Essential Technologies and Infrastructures'' of the Information Society Technologies (IST) programme in the European commission Fifth Framework programme. Key action IV is designed to build on Europe's strength in mobile and fixed communications, digital broadcasting, network infrastructures, electronic appliances, software and embedded systems integration, and in service concept innovation. The focus of the real-time systems action is development and integration of software and hardware modules solving time critical aspects and enabling embedded systems to be networked and/or communicate via the Internet. Primary application areas are control systems, machine vision and embedded web systems.

In the US, real-time embedded systems are the focus of major research initiatives. As a part of the fiscal year 2000 budget a 28 percent increase is proposed in governmental funding of information technology research, the so-called IT^2 (Information Technology for the twenty-first Century) initiative. The initiative will support three activities, whereof ``Long-term information technology research'' is one. This activity has four focal points. Two of these, ``Software'' and ``Scalable information infrastructure'', are of relevance to real-time systems. Proposed software research areas include component-based software development, active software, and autonomous software. On the network side, deeply networked systems are identified which include network-connected embedded systems. Several existing DARPA projects fit well into the IT^2 initiative. These include the ``Software for autonomous systems'' programme and the ``Software for embedded systems'' programme.

ARTES++

This section provides some background information about the national research programme ARTES, together with some indications of possible continuations of the ARTES activities after 2002.

ARTES in its current form

The enclosed folder "*Take advantage of ARTES*" provides an introduction to and overview of ARTES, its technical focus, and activities.

ARTES has in its first two years formed a network of more than 80 graduate students, 28 industries, and some 30 senior researchers at 10 Swedish universities. ARTES is a true national network, maintaining and extending the national real-time systems research community, via annual summer schools and graduate student conferences, and by supporting other meetings and activities. The international impact is also clearly visible. Sweden has today Europe's largest real-time systems research community and the visibility (in terms of accepted papers) at leading conferences has doubled from 1998 to 1999. One PhD and five licentiates have already been completed within the programme (corresponding figures for the entire network is 9 PhDs and 15 Lic.).

The current funding is totally 88 MSEK for the five-year period 1998-2002. The allocation of project funding (totally 63 MSEK) will essentially be completed in 2000, with projects gradually being completed from 2001 to 2004. Funding for the network activities are budgeted for the entire period 1998-2002.

Our experience so far has been that the combination of a network and project support is very successful. The projects need the network to exchange ideas and get inspiration. The network has got a natural base for information dissemination in the projects. We have thus learned that these two activities are closely coupled.

ARTES after 2002

We propose a continued support, at least at the current level, of both the ARTES network activities and projects, with increased focus and co-ordination of projects based on developments and experiences during the first phase.

Based on the current clear indications of successful network and projects, with strong industrial interest and support, we firmly believe in a continuation of ARTES (in one form or another). The network plays a very important role in the development of the field and in promoting industrial involvement and deployment of research results. ARTES currently supports 30 of the 80 graduate students active in the real-time systems area. Considering the relevance, impact and quality of this research effort, there are good grounds for a continued or even extended support (in one form or another). Also, ARTES plays an important role in promoting interactions between traditional and newer universities. Based on the above, our preliminary idea for a continuation of ARTES is the following:

- Continued support to the network activities, essentially in the present form, providing support for graduate courses, meeting and mobility.
- Continued project support which, based on achievements in the current phase, can be more structured and focussed. We propose an emphasis on software and system development organised into the following mutually supportive and interrelated application clusters:
  - Vehicular Systems, including automotive, avionics, ships and space,
  - Industrial Automation, including process control, robotics, etc.,
  - Telecommunication and multimedia systems,
  - Medical systems,

  with a specific bridging cluster on

  - Methods and tools for development and maintenance of embedded systems.

The clusters are briefly described and motivated below.

Vehicular systems

Aiming for better performance, higher safety, reduced manufacturing costs and lower exhaust emissions, has made the exploitation of electronics a key competitive element in vehicular systems. In fact, electronics will no longer be sub-systems to assist and improve the mechanical vehicle. Rather, it is widely believed by Volvo (and others) that embedded real-time systems will move to the forefront to become a dominant part of the vehicle. Research and development at Volvo Car Corporation and Saab Automotive in Sweden is at the competitive edge, witnessed by the fact that both of the Swedish divisions are expected to take the lead in the area of vehicle electronics for their respective owner companies.

Already in late 80's, statistics indicated that about 20% of the faults in a car relate to electric and electronic equipment. This ratio has certainly increased but should be kept down when the proportion of embedded electronics increases. Methods for diagnosis and complementary techniques for fault-tolerance are major areas of development. In car safety systems developed by Autoliv, including airbag systems and active seat support, more accurate and timely recognition of crash and non-crash pulses is a major field of attention. Variable compression and variable valve timing are elements in a new engine design by Saab Automotive, aiming at better emission control and optimisation. Further, Scania is at the leading edge of developing advanced engine and transmission control aiming at for example improved fuel economy. All of these improvements use technologies that are dependent on research and education in the area of real-time systems.

However, manned and unmanned vehicles (aerial as well as terrestrial) and aircraft safety are few "details" in the grand scheme of things which is required by "dominant battleship awareness" and "disaster management"; concepts used as the backbone for development of new technologies at Saab AB. The timely and reliable access to information, delivered by secure networks and mobile agents is one of the key elements highly dependent on research on real-time systems.

Industrial Automation

Real-time computing is an enabling technology for all applications of automatic control. The majority of the requirements on hard predictable real-time systems are caused by the fact that the real-time systems in most cases are used to implement control systems. Application areas include industrial automation systems for the process, manufacturing and power industry and embedded mechatronic systems, e.g., industrial robots, vehicular systems and aerospace systems. All of these are of vital interest to Swedish industry.

The recent acquisitions of Elsag Bailey and Alfa Laval Automation have placed ABB among the top suppliers world-wide in process control and automation. The automation segment has been targeted as a future growth business for ABB. The name Industrial IT is used to denote the integration of automation and information technologies in real time to deliver integrated real-time automation systems covering the full range from the pursuit of orders via traditional or e-Commerce methods to production and delivery of finished products. Important technologies include open control systems, object and component techniques, and distribution and networking. From being by tradition a hardware-oriented company, ABB is currently in the transition towards a software and knowledge-oriented company.

Several of the existing ARTES projects are addressing issues of relevance to industrial automation and embedded control systems. Examples are scheduling of control systems, co-simulation of real-time kernels and control systems, architectures for scalable and reconfigurable mechatronic system, and embedded distributed control systems.

Telecommunication and multimedia systems

Ericsson's internationally leading position has made Sweden a main player in the design of the underlying infrastructure for the Internet. In addition, companies using this infrastructure to develop Internet-based products, systems and applications are formed and grow at a rapid pace. The race for wireless, broadband Internet has just started. Many see this as the next major expanding area in the telecom market. This includes the vision that short-range wireless communication between embedded computers will be a part of people's everyday life in a way hard to imagine today. Applications most often mentioned are multimedia, voice over IP, and video. . The next generation applications will be interconnected appliances found both at the office and in the home. The picture will be even more complex when also industrial applications are considered, demanding precise predictions on delivery time and quality of the information. In fact, no part of society will be left unaffected.

Scandinavia and Sweden is leading this development. American companies move their development sites to Sweden in order to catch the wireless application market. If we want to stay in a leading position, we need to be in the front using our edge in wireless communication and embedded real time computing. The designers of such future communication systems are faced with challenging demands. The underlying infrastructure is built from a number of interacting building blocks and involves a variety of technologies such as fibre links, wireless transmission channels, high-end compute servers as well as mobile terminals with limited capabilities.. The diversity in networks technologies, with a large difference in transmission characteristics and the diversity in clients capabilities, ranging from handheld PDAs, embedded computers in smart pens, micromechanical devices in medical probes, to high end clustered multiprocessors will require flexible and downloadable software that adapt to application, network and client capabilities. In fact, in their report to President Clinton in February 1999, the PITAC committee emphasized more research into scalability issues of the systems supporting this infrastructure (http://www.hpcc.gov/ac/report/. See Sec. 3.2 and 3.3).

Designers of future telecommunication systems must have a solid foundation in a holistic system design approach. The key goal is to develop design methodologies that allow designers to make engineering tradeoffs across tailor-made and adaptive hardware and software components under challenging demands on performance and real-time function. Important areas in which research must be directed are in distributed and self organising systems, mobile computer systems attached via wireless links, communication systems that scale from small to large systems, and content application infrastructure, especially for interconnected embedded systems

Many of the ongoing research activities within ARTES are addressing issues in some of these areas, including development of design methodologies to meet challenging performance demands using multiprocessor technology under real-time constraints. Projects address processing capacity and real-time issues in database systems, in virtual reality applications, and in telecommunication servers. Besides Ericsson, Axis Communications and ABB Robotics are examples of companies involved. Other ARTES projects address real-time issues for the communication systems, including high-performance fibre-optic networks as well as short-range wireless systems. Predictable and reliable wireless communication is expected to be a key research area for the coming industrial use of mobile Internet and other wireless technology. Examples of companies involved are Hassbjer MicroSystem, Ericsson, and Carlstedt Research and Technology.

Medical systems

The amount of computer controlled equipment used in medical therapy and examination is rapidly increasing. Swedish-based companies, such as Siemens-Elema and Datex-Ohmeda, are major players in this development. There are indications of emerging science fiction like therapy methods, such as advanced telemedicine and fleets of micro mechanical surgical robots navigating through our bodies to cure illnesses. We do not know exactly which direction this development will take. But what we do know is that all this equipment is highly safety-critical. Thus, there is an apparent need for rigorous methods for system development, analysis, and quality assessment. Current methods for design of safety-critical real-time systems provide a good base for development of such methods.

One of the most urgent medical area for IT-products is home care. The number of elderly people will increase and medical care of them in the home may not only cut hospital cost but may also increase the patients' quality of life. Embedded computers in medical equipment can be carried by patients. These carried computers can be in contact with a stationary computer in the home via wireless links. Home care put stringent requirements on reliability, safety, integrity, real-time and legal rights, besides the software and network complexity.

In applications such as telemedicine and training of staff, Virtual Reality (VR) has a potential of providing efficient and cost-effective solutions. VR is a technology that has been enabled by the availability of cost-effective multiprocessor servers to meet the challenging performance demands of modelling complex scenes in real-time. VR has been used in advanced computer games for some time, and is also being frequently applied in advanced CAD tools to support virtual prototyping of a variety of products. In medicine, VR based simulators are being developed to support training sessions for surgeons. These simulators should provide a high realism in terms of visual as well as haptic response and therefore impose extreme demands in terms of processing capacities in real-time. In one of our projects, design principles for computer graphics algorithms involved in such applications are being studied.

Methods and tools

Many different methods and tools are used in the development of embedded systems, including compilers and operating systems, analysis techniques, formal modelling and verification, testing techniques and debuggers. There are several Swedish companies that are successful internationally. These include, ENEA which is developing the OSE real-time kernel, IAR Systems which is developing compilers and design tools for embedded systems, Telelogic which is developing specification and implementation tools, and Volcano Communication Technologies which is developing real-time kernels and tools for timing analysis. There are companies, such as Prover, Industrilogik, Carlstedt Research and Technology and TietoEnator Teknik, which assist developers in specifying, modelling, analysing and implementing embedded systems.

Many embedded system applications impose specific requirements on the development process. For instance, most applications require some type of timing analysis, and safety-critical applications require rigorous timing and reliability analysis. As these systems often straddle several domains (e.g., hardware vs. software, user interfaces vs. operating systems) and have conflicting requirements (timeliness vs. functionality vs. cost), there is a need for methods and tools for handling the increased complexity of specifying, developing, documenting, or using such systems.

There are many ARTES projects currently developing and extending state-of-the-art real-time design methods and tools. This work should continue in the next period, but be more focused on providing complete solutions appropriate for the application clusters. There should additionally be an increased emphasis on correct behaviour during the entire life cycle (as outlined above).

Conclusions

- Embedded systems is the dominating use of computers, and will increase even further as we are entering the era of pervasive computing with massive amounts of co-operating computers controlling virtually all devices in our environment.
- Software is the key component in embedded systems, providing added value and required behaviour.
- Embedded real-time software and systems are major products of Swedish industry.
- The over all complexity of embedded systems will grow, as they are introduced in new applications, and as requirements on flexibility, integration, external communication etc. are increasing.
- Research and education into embedded systems is vital for Sweden to stay competitive.
- A national research network with associated research projects has proven efficient in strengthening the area.

About this document

This document is edited by ARTES programme director Hans Hansson (Mälardalen and Uppsala universities), with contributions from ARTES chairman Bengt Asker, Per Gunningberg (Uppsala Univ.), Peter Lidén (Volvo Technical Development), Roland Grönroos (Uppsala Univ.), Simin Nadjm-Therani (Linköping Univ.), Hans Skoog (ABB Corporate Research), Bertil Svensson (Halmstad Univ.), Per Stenström (Chalmers), Jan Torin (Chalmers), and Karl-Erik Årzén (Lund Institute of Tech.).

Additional information about ARTES is available at http://www.artes.uu.se/