Information Processing at Universities – Organisation, Services, and Systems

Statement of the
Commission on IT Infrastructure
for 2016–2020

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Content

Commission on IT Infrastructure

The Commission on IT Infrastructure (KfR) deals with fundamental issues relating to information provision and processing at universities and draws up recommendations for medium-term planning. As a subcommittee of the DFG Joint Committee, it evaluates the results of reviews of major instrumentation proposals involving IT systems – within the DFG's general research funding activities, the Major Research Instrumentation programme according to Art. 91b of the German Basic Law (GG), the Major Instrumentation in Research Buildings programme and the State Funded Major Instrumentation programme. It is concerned with fundamental issues relating to the IT infrastructure of universities and hospitals and prepares recommendations on overall IT concepts, IT installations and IT network concepts. The commission also monitors developments in IT, places them in an international context and shares its views on relevant issues.

The commission consists of academic members elected by the DFG Joint Committee for a period of three years (since 2016: four years). In 2015 the commission had the following academic members:

- **Professor Dr.-Ing. Birgit Awiszus** (Chair)
  Technical University of Chemnitz
- **Professor Dr. Björn Bergh**
  University Hospital Heidelberg
- **Professor Dr. Odej Kao**
  Technical University of Berlin
- **Professor Dr. Peter Loos**
  Saarland University
- **Professor Dr. Thomas Ludwig**
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- **Professor Dr. Ulrich Rüde**
  University of Erlangen-Nürnberg
- **Professor Dr.-Ing. Christiane Thielemann**
  Aschaffenburg University of Applied Sciences
- **Professor Dr. Ramin Yahyapour**
  Gesellschaft für Wissenschaftliche Datenverarbeitung mbH Göttingen (GWDG)

1 Summary

It is hard to overestimate the importance of information technology (IT) in a university context. It permeates almost every area of research and teaching and is omnipresent in administrative processes, medicine, and libraries, for example. The Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) is concerned in many ways with the use, establishment, and development of the IT infrastructure at universities. This can be seen firstly in project funding, the object of which may be the academic use of IT or methodological and technological basic research in the field of IT (e.g. in the Priority Programme SPPEXA). Secondly, the DFG also offers funding programmes intended specifically for infrastructure as well as review services for universities and funding providers used to evaluate investment projects from an academic and technical point of view. In this way, the DFG contributes to quality-assured infrastructure development in accordance with uniform national standards.

Previous DFG recommendations on information processing at universities have already identified that it would often be impossible to incorporate IT investments in a modern or adequate way were they not integrated in clear strategies, priority areas and university-wide or indeed nationwide concepts. This statement by the Commission on IT Infrastructure, the DFG's evaluation body for IT-related proposals, explicitly underlines this point. Instead of being simply an incremental continuation and updating of older recommendations, the document with its new content structure intentionally examines the various levels at which IT facilities issues at universities to be addressed.

The section "Strategic Considerations in IT " explains the crucial importance of a university-wide IT concept and expresses the assumption that all universities must address this issue. The embedding of concrete proposals in a university IT concept therefore becomes standard procedure. University leaders are equipped with guidelines that provide modern framework conditions for the necessary ongoing development of IT strategies. Incorporation of the topic at university leadership level, the balance between central and peripheral structures to be developed individually at each university, and clear responsibilities in IT governance are all decisive factors in the efficient use of resources and optimised IT usage for research and teaching.

The section "Organisational Considerations ", which mainly addresses the management level of central facilities and services, describes minimum standards for IT provision at universities. It identifies different layers of integration and provides guidance as to basic services, application services and service portals. This section therefore covers all IT services which are or should be available at virtually every university in Germany. Special emphasis is given to data protection and services from third-party providers, especially cloud services and their benefits and risks. Recent developments in data storage and capacity provision are therefore considered, and funding opportunities for cloud solutions in an academic environment are presented.

IT would be inconceivable without the hardware it depends on. The section "Technical Considerations" deals with the basic technical requirements for universities, including networks, computers of different performance classes up to supercomputers, and storage and archive systems. Nowadays energy is a key factor, since operating costs represent a significant proportion of total costs. In larger IT structures, investments, operating costs and staff costs are all part of the consideration of total costs, which, over the intended time period, provides a decision-making basis for funding providers – in the case of operating and staff costs, usually the universities themselves. Finally, the key role of software is highlighted; a relevant cost factor with special features of its own in relation to licence models.

IT may also play a dominant role in certain subject areas not prominent at all universities. The chapter "Special Profiles" describes two such areas with specific recommendations.

In terms of supercomputers, the basic technical requirements of which are discussed in the previous chapter, the Commission examines the importance of simulation-based research. The sustainability of the software used for this type of research, often developed in the academic environment, is of crucial importance to its medium- and long-term use. The establishment of new directions in scientific computing is very evident and needs to be adequately incorporated in academic research and teaching.

IT in university medicine is also of crucial importance. The close linking of research and teaching with healthcare provision also permeates IT systems and presents special challenges, for example in relation to patient data, research data and translation. Through its review service, the DFG provides an advisory function that covers not just the actual proposal but also the strategic orientation and integration of IT within processes in medicine to be considered also at supra-local level.

By its very nature, information processing does not take place only in individual locations. It is already essential to think beyond the limits of the university, an approach likely to become increasingly important in the future. In the section "Funding Considerations / Funding Strategy", nationwide funding providers are called upon to develop suitable supra-local concepts and use them as the basis for acquisition measures. Planning modern IT structures demands the professional support of government ministries and other funding providers for concept development. The dynamic development of information processing makes it necessary to adapt funding opportunities to respond to the growing importance of service processes.

The statement concludes with a description of "Funding Opportunities". This section explains which funding programme is suitable for different types of investment projects. One challenge in the further development of funding schemes will certainly be to find an appropriate response to the disappearing boundaries between investment and operation and to reflect this in opportunities for proposal submission.

This statement on information processing considers challenges relating to IT infrastructures at universities from various perspectives. These are not solutions, but rather convey the central message that this important topic must be continuously developed within the universities themselves. This may result in different approaches or strategies at different institutions. The awareness and discussion of these scenarios is an integral part of a scientific discussion process on the question of how IT can be used to deliver maximum benefits for research and teaching. Due to the considerable dynamism of IT development, no final point can be reached, so it is likely that this statement – like previous versions – will have to be amended to reflect future developments.

2 Strategic Considerations in IT

The basis for efficient, reliable and secure IT is a university-wide IT concept that describes the use and strategic development of IT and should be continuously updated. The IT concept provides the strategic framework for a long-term IT development. This section deals with issues relating to the strategic orientation of IT and the associated organisational measures as part of the university strategy. This section is therefore aimed primarily at university leaders and CIOs.

2.1 Digitisation of research

Digitisation is changing the world of research. In recent decades it has entered a growing number of fields, not only in the natural and engineering sciences but also in the humanities (giving rise to the concept of digital humanities or e-Humanities). Data-driven research is producing new routes to knowledge. As well as ways to make artefacts accessible, for example the digitisation of old documents, pictures and so on, the methods of analysis and evaluation used to process huge volumes of data – or 'big data' – offer new means of obtaining knowledge. Meanwhile, the Internet provides almost unlimited ways for researchers to communicate, whether to generate knowledge, access it or share it. Crowdsourcing allows a large number of external actors to be integrated in research projects through the Internet for the purpose of acquiring information, and research findings can not only be published digitally but also shared through social media.

Within the university, this plays an important role in both research and teaching. In addition to the established e-Learning, new forms of interaction such as Massive Open Online Courses (MOOC) are gaining in popularity, combining conventional teaching methods with new forms of interaction such as forums or blogs. The entire examination process can also now be handled digitally, from online exams to access to examination records.

Information technology plays a vital role in that, through the provision of a reliable infrastructure, it efficiently and effectively supports all necessary business processes. Integrated information management is therefore an important element of a university's overall strategy.

2.2 Integrated information management

Professional academic information management is a prerequisite for the effective strategic planning and coordination of a university's IT activities and for service provision geared toward the needs of researchers, tutors and students.

Today, the key requirements for the increasingly coordinated use of IT to support research, teaching, studying and administration include:

- Integration (fully IT-supported integrated processes; complete organisational and technical integration; multimedia and mobile communication; new forms of teaching, learning and working)

- Virtualisation of data, information and computing services (globally transparent access to capacities and resources)
- Life cycle management of research results data that ensures long-term storage and the provision of results in a usable form
- Integrated academic working environment (new forms of organisation, collaboration, cooperation and communication with comprehensive knowledge processing; transparent use of a wide range of services and the provision of resources and expertise; increased requirements arising from the principles of upholding good scientific practice (laboratory record book, backing up experimental data etc.))
- Insistence on enhanced, reliable quality (needs-based availability of information and resources; service levels, reliability and robustness; mobile IT use and ubiquity ('any time, any place'))
- Security and safety (data transfer, access and management, data protection, data security, integrity, protection of privacy, informational self-determination; legal framework)
- Cost awareness, economic efficiency and sustainability
- Support for collaboration in research and teaching in a regional and nationwide context and in particular for cooperation with other universities, external institutions or commercial partners to perform resource-intensive tasks (cloud services, HPC resources etc.)

The development of integrated information management within universities is therefore not an aim in itself: it ultimately serves to improve the working environment while increasing the efficiency of all university processes, and depends on the prior analysis, optimisation and integrative consideration of these processes with due regard for what is technically feasible. Modern information and communication technologies play such a decisive role in the execution of all processes in university research, teaching and administration that they are critical to the quality of the service provided and the efficient use of resources. For universities, integrated information management has thus become an essential task in planning the deployment of modern information and communication technologies.

At universities, the IT infrastructure and associated expertise is still to some extent divided among organisationally separate units as a result of the distribution of responsibilities in the past. This makes integrated information management in higher-level processes difficult, especially due to the presence of incompatible, non-coordinated island solutions which have often developed as a result of the institutional distribution of responsibilities, e.g. in the data centre, media centre, administration, faculties (often with their own smaller-scale structures) and library.

Nowadays, IT requirements are complex and manifold, and optimisation in isolated areas can only help to a very limited extent. Students and tutors expect modern information technology structures (modern teaching aids: tablets, smartphones, notebooks, wireless LAN (WLAN); largely IT-supported course organisation, from the first contact, such as the application process or pre-enrolment events, to the choice of classes, room allocation, timetable and documentation of exam results). However, the various university management bodies – facility management, examinations offices, faculties and administrative organisations – also require central support for their tasks, the efficient management of staff, student and alumni data and the handling of processes.

The effective fulfilment of these tasks requires an identity management (IDM) system with a comprehensive role concept and a directory service. This system should be used specifically to enable personalised access to portals and thus to provide all users with exactly the information which they need to perform their tasks, at any time and in any location, and which is assigned to them in their access profile (student, staff, examinations office administrator, institute secretariat, finance administrator, dean's office, university leadership, etc.).

- Persons registered in the IDM system and any changes in their status must be promptly and automatically updated from reliable sources, e.g. the central staff and student administration systems (for both the issuing and withdrawal of rights), or,
- if they come from less reliable secondary sources, they must be identified accordingly and rights denied if appropriate.

Such concepts should be implemented for personalised data in the administrative environment and for student management, especially for the purposes of collection and – due to the requirements of bachelor's or master's courses in particular – documenting assessments and exams.

If individuals and their possible various roles are reliably identified by means of an IDM system, a rights and role management system can be implemented throughout the university. Firstly, to define which individuals have which roles and which roles confer which rights, and secondly to delegate the issuing of rights such that individual organisational units can define and manage access to the services they provide by linking it to roles with associated rights. Specifically, this also applies to libraries, which provide access to chargeable services from publishing companies and other libraries through licensing agreements and can only comply with legal requirements with the help of a comprehensive and binding role concept.

IDM is both an organisational matter and a question of technical implementation. An IDM system should be supported and used throughout the university to reduce instances of parallel user management with typically lower data quality and process reliability (e.g. prompt withdrawal of roles and rights). Added value should be offered to make system or service administrators willing to hand over responsibility for access management.

2.3 Developing and implementing an IT concept

An IT concept forms the basis for integrated information management and describes the basic framework, use and strategic further development of a university's IT infrastructure.

The following structure may provide a useful guide as to the design of an IT concept:

- Objectives
- Integration in the university strategy
- Organisational structures / governance of IT
- Infrastructure concept: Servers, storage, computer rooms, network concept (see Net Commission template)
- Service infrastructure, e.g.:
    - IT infrastructure (network services, IDM etc.)

    - Basic services (e-mail, telephone/VoIP etc.), security services (firewall, antivirus etc.), data management, backup/archiving etc.
    - Application services (database systems, application software, programming environments etc.)
    - Service portals (e-learning, e-science (HPC, clouds etc.), administration portals, support/helpdesk etc.)
- IT security:
    - Firewall, intrusion detection/prevention system, certificates/public key infrastructure etc.
- Planned action areas
- Resource planning (staff, investment, operating costs)

Increasingly, reviews of funding applications expect the projects to be embedded in university-wide IT concepts, allowing long-term development considerations to be taken into account. More and more often, IT decisions have long-term impacts, and for reasons of cost-efficiency they can often no longer be viewed in isolation, instead requiring a broader perspective with due consideration of the university strategy.

2.4 Security

The number and complexity of IT systems used by university users and the services supported by these systems will continue to increase in the years ahead. This results in requirements relating to authentication and authorisation and the handling of and protection against internal and external attacks.

Universities must develop a policy to define how they intend to make what are often still uncoordinated security systems interoperable – at local level, in research groups, in university clouds and in the German National Research and Education Network (DFN). This combines the above-mentioned requirements for integrated identity management with a comprehensive security concept within the university and in interfaces with third parties.

External guidelines laid down by the Federal Office for Information Security (BSI) and legal requirements must also be observed. This also means that methods of risk assessment and disaster recovery must be included in development plans for university IT infrastructures.

In terms of the use of personal data, there is growing conflict between greater functionality or convenience on the one hand and the protection of private data and informational self-determination on the other. The increasing use of public cloud services (such as Dropbox, Doodle or Google Docs) is blurring these boundaries. The right to informational self-determination and privacy are basic needs, but the emergence of social media and cloud services has greatly altered the way in which they are handled.

Universities must develop suitable strategies to adequately protect sensitive and valuable data and comply with legal data protection requirements. This calls for increasing differentiation and classification of data in order to develop a multilevel security concept. For example, in all probability universities will hold data with lower security and protection requirements for which the use of external services could be contemplated. But they also hold highly sensitive data that needs a high level of protection, for which the standard security level at universities is inadequate.

Typically, universities have established concepts for IT security and data protection and appointed people responsible for data protection and security. These models need to be continuously developed and reviewed. Growing requirements and more differentiated perspectives also demand appropriate structures within universities, which must offer sufficient resources and knowledge. It is the responsibility of university leaders to ensure that an appropriate security infrastructure is put in place.

2.5 Management / responsibilities

Until recently, decisions on the acquisition of technical components and the operation of the basic infrastructure were often made locally and applied to local environments. The technical development of computer and communication capabilities and the growing complexity of application software, which is partly due to increasingly interlinked processes, have made it necessary to apply global optimisation factors and to focus on integration and homogenisation in basic infrastructure planning.

It is necessary to find a balance between central and peripheral responsibilities while achieving a harmonisation of processes across organisational boundaries to synergistically merge redundant tasks and minimise them in the interests of efficiency. Process optimisation and comprehensive solutions can create potential for improvement both within and between universities.

Before this type of restructuring can be planned, a clear division of responsibilities must be defined in the IT governance and there must be close coordination with the university leadership as part of the university strategy. Many universities have introduced CIO models to establish university-wide strategic coordination for information and communication.

In university practice there are four different types of CIO:

- Strategic CIO with management function: A vice-president is explicitly responsible for information management. The chancellor may also have some information management responsibility.
- Strategic CIO with staff function: Information management is coordinated by an academic staff member or IT manager on the president's staff.
- Operational CIO: The head of a central information infrastructure facility also serves as the university's CIO.
- Collective CIO: The CIO function is performed by a steering committee of two to three people, but unlike a traditional senate committee, they have direct decision-making powers.

Each type of CIO has its advantages and drawbacks. The most suitable form depends on the circumstances at the university in question and more particularly on the individuals concerned. A strategic coordinating plan developed in close cooperation with the university leadership is deemed important in order to coordinate strategic IT development with the university strategy and implement it.

Overall responsibility for the necessary change process in the universities is shared equally by all members of the university leadership, because information and communication technology is of crucial importance to research, teaching and administration. In most successful implementations the CIO also handles the optimisation of processes in the organisation as a whole.

2.6 Cooperations between institutions

The internal optimisation of processes, organisational structures and a university's focal areas of research and teaching typically results in university-specific solutions for the efficient use of IT. However, this process cannot stop at the boundaries of the university. Increasingly, universities are forming networks to cooperate in research, teaching and administration. Inter-university cooperation at state and federal level, for example the German National Research and Education Network, the Gauss Alliance, virtual state universities and jointly operated library portals, will become more common for reasons of efficiency. University leaders would be well advised to take this factor into account in their strategies, in spite of – or indeed because of – the growing competition between universities.

Specific tasks in research and teaching call for resources that demand an investment volume that may be beyond the capacities of an individual university. Scientific high-performance computing (HPC) is a typical example, the topmost components in the provision pyramid being procured in the form of national facilities and research supercomputers in the federal states in agreement with the responsible bodies of the German Council of Science and Humanities and the DFG. This also ensures that the necessary access infrastructure exists throughout the country or federal state and access authorisation is issued on the basis of scientific criteria through a process of review by advisory bodies.

Some federal states (for example Baden-Württemberg) have already introduced concepts that develop the idea of cooperative provision at state level for HPC and other services (e.g. data, backup, cloud). Within the spectrum of basic services provided by university IT infrastructure, inter-university networks may represent efficient solutions without limiting the desired profiling of individual institutions. Basic services include the system administration of workstations for researchers as well as students, e-mail services, data storage, archiving, backup, security concepts, software licences and so on.

As result of recent advancements, firstly in virtualisation and cloud computing and secondly in the standardisation of IT services with a high degree of automation and economies of scale, cost-efficiency has become an essential element of an IT strategy (see 4.7). In the operation of joint IT infrastructures, based on concepts and implementations spanning several universities, it is now possible to exploit synergies on a scale that was not previously achievable. In the future, more use must be made of these synergies. This might even result in DFG-approved infrastructures being installed not at the applying university but at other universities or university consortiums. In the interests of efficiency, these infrastructures are operated locally on behalf of the partners. Local research must still be possible in this scenario. Suitable cooperation agreements should be developed to balance the interests of all parties.

2.7 Sustainability of the IT strategy

Because IT is not an end in itself and has grown to be of vital importance to virtually every area of a university, the IT strategy must be seen as part of the university strategy. IT is a vital aspect of a university's core tasks in teaching, research and professional training. Without appropriate IT support, many of these tasks simply could not be performed. In addition, networking and mobility offer new opportunities, which are actively demanded by both students and staff. To satisfy these requirements and to exploit innovations, the continuous development of information technology is essential.

This is a task, which requires not only appropriate governance but also the ongoing review and amendment of the IT strategy in response to new demands and developments. A clearly defined IT strategy with an IT concept provides a basis on which to place individual measures within a larger context. Such a concept should be regularly updated and harmonised with the university strategy.

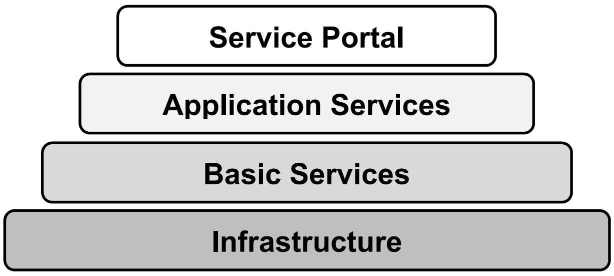
Increasingly, the sustainability of individual measures presents a significant problem. Securing long-term infrastructure funding presents challenges to universities. This applies especially to the prevalent separation of investment costs and ongoing operating costs (including staff) in IT, due to specific types and sources of funding. However, the follow-on costs of IT investments must be adequately taken into account before an informed decision can be made. Follow-on costs are therefore an important factor to consider when applying for funding and reviewing funding applications. It is also important to ensure that there are sufficient members of staff to operate the IT infrastructure. It should be noted that job profiles in IT provision have evolved and will continue to evolve. Staff members should be prepared for these changes and brought on board through basic and advanced training measures.

3 Organisational Considerations

To assure IT provision at a university and support the outlined core processes, an efficient and reliable service infrastructure is needed. The purpose of this section is to describe the required minimum standards for IT provision at universities; it is aimed at the managers of central facilities (e.g. data centres or libraries) and CIOs.

3.1 Service infrastructure

The IT service infrastructure comprises the staff and facilities required for digital information provision and processing, digital communication and media use in all organisational units of the university. The architecture refers to the dependencies and interaction of services and other IT components. The architecture most commonly used today consists of four layers of integration shown below.



The infrastructure level is the technical basis for services. It comprises systems, connecting communication networks and other related technical infrastructure (hardware, technical monitoring, network connections and technical communication systems).

On the next level are basic services, which enable the standardisation of interfaces and meet the heterogeneous usage requirements which a university's IT facilities are expected to fulfil. These include, for example, systems and middleware (virtualisation, safeguards against failure, accounting etc.), systems for data storage and backup (data management and archiving) and security solutions (firewall, antivirus protection, mail filtering etc.). The vast majority of basic services are available either commercially or as mature open source solutions and should not be developed at universities, unless for research projects.

Application services are based on basic services and mainly comprise components such as application systems (e.g. software packages, database systems), application software (e.g. officeware, libraries) or programming environments and tools.

Finally, the service portal is the application-related overall integration layer in that it provides central, standardised access to business processes and the associated information, applications and services. Given the growing use of mobile devices to access services, the service portal should be accessible and usable on such devices.

3.2 IT components required by a university

The elementary IT components comprise systems for computing, data and communication services and application servers. These components are usually purchased 'off the shelf' and operated by trained IT staff.

The university network is the backbone of the university's IT infrastructure. It is recommended that a network operation concept be drawn up and published and that all activities be geared towards the principles of service management, e.g. on the basis of ITIL.

A university-wide data repository forms the basis for the development and interconnection of IT services. Access must be available anywhere and at all times from different devices.

The portfolio of a university-wide IT provider generally comprises traditional services: e-mail, internet, software distribution, tools for joint working on documents, account management, domain management, user support, security management (certificates, VPN, abuse handling, monitoring, antivirus, spam protection), storage management (file systems, data backup, data archiving, Apache Subversion (SVN)), hosting and housing, database provision, IT procurement, videoconferencing, and similar services. The modern IT provider's portfolio also includes the following services:

- Campus management: An integrated system for resource management and the management of the student life cycle forms the backbone of modern university administration.
- Identity management: To provide personalised services, multi-institution processes and cooperative approaches require a trustworthy, reliable and up-to-date central identity management system that administers all members and their roles and rights. This is supplemented by a cross-university single sign-on process for the identification and authentication of network users, the protection of e-mails with signatures and the development of a public key infrastructure.
- Research information systems, as part of institutional information systems, support the provision of information for research reporting.
- Learning management systems: e-learning and/or blended learning complement classroom-based learning with added value in the form of digital material and are a strategically important core service of university IT. The main aims are to actively involve students in the learning process and to reach out to new target groups of learners through the digitisation of learning opportunities, for example in the form of Massive Open Online Courses (MOOC).
- E-science: Scientific value-adding processes require cooperation platforms for researchers at a given university and their global partners, for example to facilitate the internal and external exchange of information, the creation of shared documents, the use of shared calendars, project planning and the management of shared resources.

These services may be provided by the local IT provider (university data centre), a regional/state network or a commercial provider. As a matter of principle the local IT provider must supply or organise the necessary staff and equipment for all areas of provision. This provider also has operational and regulatory responsibility for the locally distributed cooperating IT system. Above all, this IT service centre serves as a service and competence centre for all matters relating to the service infrastructure.

3.3 Data protection

The number and complexity of IT systems used by university users and the services supported by these systems will continue to increase significantly in the years ahead. This gives rise to data protection requirements to which universities should give special attention in the form of a security concept. In the university environment, particular attention is paid to the concept of freedom of research and teaching. At the same time, the privacy and intellectual property of the individual must be protected. Data which accidentally ends up 'online' is almost impossible to erase partly because the definition of privacy in German law differs from that in other jurisdictions, for example the USA. So security concepts must be continuously updated and improved with reference to the university's business processes and with due consideration of security and data protection considerations. The aim must be to achieve a continually repeated cycle, geared towards the business processes, which enables the implementation, monitoring, evaluation, and improvement of all relevant measures based on objective criteria.

3.4 Working with services from third-party providers

The services of strategic importance to a given university must remain in the hands of that university so that they can be developed to the desired level of detail. For other services, third-party providers may be considered – especially within the framework of multi-location concepts – particularly if this would result in greater cost-efficiency. But in order to competently assess the quality and future suitability of outsourced services, basic competence should still be retained. However, an examination of the levels of a service architecture makes clear that neither individual users nor an individual institute should handle everything at all levels, since this degree of individual responsibility would be uneconomical and also inefficient or obstructive to the necessary university-wide integration of information management. Instead, efforts should be made to achieve consolidation in the following areas:

- Software management: licensing, software distribution, system management
- Logical data management (databases, directories, user management) and physical data handling (storage systems, data backup, high availability)
- Hardware management: merging of different servers, low-maintenance appliances, computers, peripherals, servers, multimedia devices
- Network management: passive and active network components, external connections, network management, security solutions (firewall, antivirus, e-mail filtering etc.).

To implement measures at these consolidation levels, concepts that apply across the university must be developed and realised on the basis of central guidelines and clearly allocated operational responsibilities.

Regardless of the operating model, universities must ascertain the protection requirements which apply for the use of external IT services and the relocation of data and services to a third-party provider. In a medical environment these requirements are typically very high and are also subject to the data protection legislation of the federal state in question. For example, the use of a cloud service always equates to data processing by third parties, which under data protection law is only permitted in exceptional situations with very special justification. It is necessary to clarify who is responsible for data control, including the individual steps of data transfer, storage and deletion. Typically, the assurance and monitoring of these aspects is problematic in connection with the use of cloud services (see also 3.6). In the case of larger commercial IT providers, universities and hospitals often find themselves in an unfavourable asymmetrical power relationship where it is difficult to assert individual requirements and legal claims. It is therefore necessary to consider each case individually to decide which data and services are suitable for use in external IT services. Finally, reliability, availability and costs must be defined in a service level agreement.

In a private cloud solution or community solutions in which data is held by partners within the same jurisdiction and there are no commercial interests, it is often easier to satisfy data security and data protection requirements. In most cases, cooperative solutions within the public research system should therefore be given preference over commercial external providers.

3.5 Costs / benefits of service provision

IT services involve a high initial outlay in terms of costs and support but very moderate growth per additional user, particularly where there is a homogeneous, uniform operating concept. In this context, costs consist of support, investment and operating costs. Many services can only be operated cost-effectively with a high number of users. Economies of scale can be achieved at the level of an individual university (e.g. e-mail and groupware, web servers and content management systems) and beyond (at federal state level or nationwide). From the outset, universities must develop and define funding models that ensure the long-term renewal and preservation of the infrastructure and realise investment cycles for hardware and software by means of fees for usage scenarios which are flexible in terms of time and size.

Methods for evaluating the services used are also necessary. This includes, for example, tools to monitor service usage and regular user feedback surveys to make informed decisions about the extension, modification or discontinuation of a service. It also includes an analysis of the life cycle of services, so that needs identification and the introduction of corresponding services can take place systematically.

3.6 Integration of cloud services for computing and storage

The use of cloud services has been an important IT trend in recent years. With regard to infrastructure operation, the relocation of computing and storage capacities to cloud service providers has become an interesting alternative offering advantages in terms of flexibility and cost-efficiency. The trend is supported from the private environment, where users regularly access cloud-based services without being limited by location or device. Commercial cloud providers offer a wide range of attractive services and tools to suit these needs. This raises the question of the extent to which cloud-based services could provide an alternative or addition to existing infrastructure solutions in an academic context.

The user benefits from the absence of acquisition costs for hardware and software and the option of scaling capacities to suit individual needs without the long-term commitment of a hardware purchase. The outlay for maintenance, further development, licence costs and staff costs can be reduced to a minimum, while the transfer of operational responsibility to a cloud provider also saves time and money. Another important advantage is the possibility of using shared platforms for various institutions and user groups. This can substantially simplify the work process in joint research projects and also in teaching if users are locally distributed through the use of shared storage, computing or library clouds. Users of cloud services can test and develop new concepts at low initial cost. But cloud-based infrastructures also offer many advantages for the provider: they can distribute the acquisition costs for hardware and software over more customers, achieve a high degree of standardisation and automation, accordingly. The associated economies of scale reduce management and operating costs, e.g. through the increased utilisation of individual systems and energy cost optimisation.

One central problem is the degree to which **the cloud user becomes dependent on the provider.** The more data and services are transferred to the provider, the more dependent the user becomes, as it is normally time-consuming and difficult to switch providers later on. The relationship between cloud service user and provider should therefore be analysed and evaluated with care. As regards the use of cloud services, the factors of operational reliability and data availability should be given particular consideration. The following questions provide a useful starting point:

- What backup measures does the provider offer against data loss?
- What disaster recovery concept is in place in the event of the failure of a cloud service?
- How are data and services protected against third-party access?
- What level of availability is guaranteed?
- How can data and services be migrated back to the original institution or to another provider (insourcing / change of provider)?
- In what legal framework is the service provided (i.e. what jurisdiction applies: German, European, third country)?
- What steps can be taken should a provider contravene a requirement or go bankrupt?

Generally speaking, the objectives of data protection are concerned with confidentiality, integrity, availability, authenticity, authorisation (role concepts), accountability and non-repudiation. As regards the use of cloud services and the transfer of data to a cloud provider, it must therefore be determined what protection requirements apply and whether the data needs to be protected under national law. It is necessary to clarify who is responsible for data control, including the individual steps of data transfer, storage and deletion (see 3.4).

3.6.1 Funding for cloud solutions from the DFG

Where cloud-based services offer an alternative or addition to existing infrastructure solutions in an academic setting, questions arise as to funding opportunities for services of this type since this situation constitutes a transition from traditional investments and the operation of equipment and systems to the billing of services.

In terms of applying for resources for cloud services from the DFG, a few basic conditions should be noted. The DFG is able to recommend and/or co-finance investments in infrastructures within its major instrumentation programmes; operating costs are however excluded. Because cloud services are considered 'services' (*Dienstleistungen*) for legal purposes, the current distinction between investments and operating costs is no longer applicable, or only to a limited extent. It is apparent that this distinction will not satisfy academic requirements in the long term and that a new approach is called for.

However, the DFG can recommend and/or co-finance investments in the cloud infrastructure for private and community cloud solutions and thereby support best practice models. The use of cloud services, for example in DFG projects, will generally come under core support and, like the use of a service in a data centre, cannot be funded through additional support. Exceptions will only be permitted with a special justification, which must make clear that a particular project has additional and specific requirements that extend beyond basic provision.

It will become increasingly important to consider the total cost of ownership for services or experiments, to make services such as cloud services comparable with hardware or software purchases and if necessary obtain funding for them. The sustainability and cost-effectiveness of solutions should be presented, as figures from public data centres show that commercial cloud solutions are typically not cheaper than in-house operating models. However, this assumes a high level of automation and a critical size for economies of scale. Preference should therefore be given to community cloud solutions delivered within the research system over private and external cloud services. For community cloud solutions, an appropriate legal framework must be established for the sharing of resources. Questions relating to tax issues, public procurement law and the billing of services, for example, must be resolved.

An examination of the current technical and legal parameters reveals that at present, the use of cloud services within a project requires a careful cost/risk analysis. Funding opportunities are limited due to the legal requirements and a differentiated appraisal is needed for funding applications. This should cover the following points, among others:

For infrastructure proposals (see section 7):

a) A total cost of ownership analysis including running costs and, for private or community clouds, the required long-term staff funding. A tabular summary covering a five-year period should be provided.
b) An analysis of the longer-term use of cloud resources, the associated funding model and the replacement scenario in the event of a change of provider or termination of service use.

For project proposals:

a) Before submitting a proposal for the use of commercial cloud services, it is recommended that the availability of alternative services from local data centres, other public institutions or campus networks should be evaluated.
b) A statement from the local data centre manager or a senior member of the IT team on the nature and scope of resource usage and any alternative services (particularly within the research community) should be attached to the proposal.
c) If the intention is to use external cloud providers, the applicable requirements of data protection law must be assessed. This is especially important where personal data is handled.

The statement should also explain how long-term data archiving is to be ensured, particularly with respect to the recommendations on good scientific practice.

4 Technical Considerations

IT systems in a broader sense, i.e. hardware and software, provide the technical foundation for the provision of IT services in research, teaching and university administration. The following sections describe different categories of hardware concepts that crop up regularly in applications for investments. Together with the required software they form the IT system, which must also be considered from the perspective of operating costs in each individual case. This section is aimed at the CIOs of institutions and the heads of data centres.

For computers we add a further subdivision to the capacity pyramid, reflecting the growing use and diversity of mobile devices at the lower end and activities relating to European supercomputing centres at the upper end. This allows different disciplines to be provided with suitable IT systems in a way that meets their needs. Conventional desktop computers and computer suites are in decline, as both students and researchers increasingly use notebooks and tablets as their basic working equipment. Finally, the subject of IT systems includes the topic of software, which now accounts for a significant proportion of IT acquisitions at universities. It is often the availability of capable software and not the hardware it runs on, that presents a problem.

4.1 Networks

The network infrastructure is the heart of a distributed information and communication system. As the basic infrastructure, it must offer sufficient and consistent performance to be able to support current and emerging communication services and distributed systems or applications. The network infrastructure comprises local and internal areas, nationwide networking and access to international networks. Activities in the area of cloud computing make access to international networks highly important.

The growing integration of telecommunication services such as telephone and fax on the one hand and data communication on the other cannot be ignored. This can be seen in developments such as VoIP, voicemail, videoconferencing and the linking of telephony infrastructures via the German National Research and Education Network and the Internet. With the wider availability of mature, stable VoIP technologies, traditional telecommunication systems are gradually being replaced through a process of migration, and this is equally true in universities. In addition, the potential synergies offered by the merging of data communication and telecommunication have been identified and in many cases these organisationally separate areas of responsibility have been merged. In the planning of a migration project, universities should seek to avoid dependence on specific manufacturers wherever possible. Where such projects are being planned, consideration should be given to network components with the properties required for VoIP and the issue of redundancy when network infrastructures are extended or replaced.

WLAN and other mobile communication technologies offer the attractive possibility of greater flexibility in network design, be it in addition to an existing fixed network or a stand-alone alternative to a fixed network with a dedicated limited scope (but with an Internet connection) or to connect remote branches via point-to-point bridges. This allows existing applications to be used with greater convenience with the help of mobile workstations that are not tied to a particular location. The combination of wireless and wired connectivity opens up significant potential for innovation. WLAN technology is primarily a solution for mobile workstations, but it may also be useful for stationary workstations with limited total bandwidth and security requirements. Normally, a cabling infrastructure should be installed to connect the WLAN cells (together with a power supply); the complete absence of a cabling infrastructure may only be considered in exceptional cases.

The demands placed on networks will grow significantly in the years ahead if modern mobile devices (such as smartphones and tablets) with an array of new functions become an integral part of research-driven collaborative working and therefore need to be integrated into networks. This represents a new complexity in network infrastructure, which must be adequately addressed and probably supported with additional staff, particularly in the context of the security architecture required in a university.

This is especially applicable in university hospitals, where WLAN is increasingly being offered as a service to non-researchers, primarily patients. Here, the stricter data protection requirements must be satisfied by means of special measures such as demilitarised zones, separate networks and so on.

The DFG's Net Commission has published its own notes[1] for proposals relating to network infrastructure in universities and university hospitals, which should be followed.

4.2 Desktop computers and local servers

Today more than ever, the operation of modern universities and research institutes requires the availability of and (remote) access to computer and storage systems of all types and performance classes. While the previous sections looked at aspects of network concepts, the following sections will consider the requirements that apply to computers and software as well as (potentially mobile) end devices themselves.

4.2.1 Desktop computers for students

Previously, IT provision for students demanded a comprehensive infrastructure. Nowadays, however, most students have their own notebook or tablet and/or web-enabled smartphones, with the result that only a small number of computers needs to be provided as access points and for special requirements. The task of institutions is now to provide an adequate complete network infrastructure (wired and wireless). In addition, it must still be possible to use systems acquired as part of the Researcher Personal Computer Programme (WAP) for training purposes, for example in teaching with a research element (final dissertations etc.).

[1] DFG guidelines 21.202: Notes on Proposals for Networking in Universities and University Hospitals (only available in German):www.dfg.de/en/dfg_profile/statutory_bodies/joint_committee/it_infrastructure/net_commission

4.2.2 Desktop computers for researchers

Desktop computers for researchers can still be applied for and funded through the Researcher Personal Computer Programme[2] (WAP). It should be noted that computers applied for through the WAP must be integrated in local structures (clusters) and supplemented by servers (local, central or virtualised) for central services. This must give rise to a recognisable synergy effect. Suitable concepts for operation and usage, including data archiving and backup, should be developed and presented. The integration in the university's overall IT concept must recognisably result in links to the data centre above and beyond the local structures and embedding in the rest of the IT structure.

Selection of components. Nowadays, the large majority of tasks can be handled with low-cost PCs. The use of high-quality components is recommended in the interests of reliability and minimal maintenance. In terms of software, preference should be given to standard solutions with open storage formats and open interfaces. Open source environments should be encouraged wherever possible.

Mobile components. Today a wide range of mobile components is available in the form of notebooks, tablets and web-enabled smartphones. In some projects these have the potential to create new possibilities and impetus for innovation. In addition, more and more researchers are using notebooks as their desktop computers, with the stationary machine being replaced simply by a docking station. In WAP proposals, mobile computers are therefore treated in the same way as stationary ones as long as they can be categorised as major instrumentation in the aforementioned sense and are justified in the proposal.

4.2.3 Local computer clusters and storage systems

For applications that require a very large amount of computing or storage capacity, for example in numerical simulation and/or data-intensive research, local computer clusters and storage systems with typical costs of up to around €500 000 may be required. However, their acquisition and local operation only makes sense if full use can be made of them locally, if they are equipped with the necessary hardware and software for specific tasks, and if they can be properly operated. As an alternative, it will often be more advisable to enlarge a central cluster with a dedicated usage right, especially with regard to efficient operation. Systems such as this can supplement central high-performance computers and supercomputers and reduce their workload. Acquisitions of this size require special scientific justification and a detailed operation, usage and embedding concept developed in agreement with the CIO or IT service centre.

If a local computer cluster is a suitable infrastructure for a working group, a local storage system that provides data storage during scientific work processes may also have to be considered. RAID systems, which permit the pre- and/or post-processing of large volumes of data with short access times, could be used. Long-term data archiving, the backup of results and the making available of data to third parties should generally be handled with central servers.

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[2] DFG guidelines 21.11: Guidance for WAP proposals in the State Major Instrumentation programme: www.dfg.de/formulare/21_11/21_11_rtf.rtf

Given the pace of technological development, the systems purchased should offer the highest performance possible and the latest technology as appropriate to foreseeable needs. It is not usually advisable to try to extend service life by buying systems with flexible upgrade options. Instead of upgrading after two to three years, it is usually more cost-effective to buy new systems and continue using old systems for other purposes. The follow-on costs should be kept low by purchasing systems with a multi-year warranty.

The cost-efficiency calculation should also take account of operating, maintenance and staff costs. In particular, annual energy costs should also be considered. Once the warranty has expired it is often advisable to take faulty equipment out of service. When purchasing software, universities should make sure that the purchase price includes not only updates but also the delivery of new versions. Short-term licences should be avoided.

4.3 High-performance computers and supercomputers

For many of the sciences, high-performance computers and supercomputers are indispensable research infrastructures to obtain new knowledge. The German Council of Science and Humanities underlined their importance in its Recommendations on the Funding of National High-Performance Computing and Supercomputing in Germany[3] in April 2015. The restructuring taking place as part of the planned National Centres for High-Performance Computing and Supercomputing will have an impact on the statements made in these recommendations. The following two sections are based on the status of acquisition planning prior to this restructuring.

4.3.1 High-performance computers

Where there is a scientifically justified need, universities can also request funding for their own high-performance computers with an investment volume of typically up to approximately €5 million. These computers should always be integrated in a provision concept for the whole federal state. They should also be accessible to working groups and researchers for whom the operation of their own high-performance computer would be uneconomical but whose needs justify the use of such equipment. These systems are also used for the qualification of project team members and thus the preparation of projects and programs for supercomputers. In this context, institutions should furnish evidence of qualification and training concepts, which could be embedded in a university strategy for simulation-based and data-driven sciences (CSE), for example.

Where several universities within a federal state (or several federal states) need high-performance computing capacity, this can also be covered by shared (state) high-performance computers with an acquisition volume of approximately €5 million to €15 million, as provided for example by the members of the Gauss Alliance, an association of Tier 2 high-performance

[3] WR-Drs. 4488-15 www.wissenschaftsrat.de/download/archiv/4488-15.pdf

computing centres (i.e. below the level of national supercomputers). All high-performance computers should be managed on the principle that computing time is allocated according to scientific criteria and only for projects which cannot be handled with lower-level systems.

High-performance computers – like the supercomputers discussed below – directly support research in that they are both the subject of research, when they are used to develop new solution strategies, and also research instrumentation, when they are used to solve very complex problems by means of processing-intensive simulations – problems that could not otherwise be tackled or only at prohibitive cost. At this point it should be noted that in 2008 the Joint Science Conference introduced a so-called programmatic-structural line, "High-Performance Computers", on the recommendation of the German Council of Science and Humanities. The DFG was significantly involved in preparing the slightly modified criteria for funding eligibility in accordance with Art. 91b of the Basic Law (GG). The Gauss Alliance subsequently made the fulfilment of these criteria a requirement for membership.

4.3.2 Supercomputers

Certain classes of applications, mainly in the area of numerical simulation and optimisation (often referred to as grand challenges), require supercomputers, the acquisition value of which is currently far in excess of €15 million. The availability of such systems is an essential prerequisite for the competitiveness of German research and technology. Acquisitions must be coordinated to ensure that at least one latest-generation computer, which is among the most powerful in the world, is always available in Germany.

Supercomputers must be integrated in the national research network in such a way that all universities can access them for research purposes. In the case of remote access to these systems, the network administration must permit peak utilisation loads as many tasks require high throughput rates as well as high computing capacity. In particular, the use of results data must primarily take place locally through visualisation systems. Modern research also requires high-performance storage and archiving systems.

Due to the high level of investment, it must be ensured that supercomputers are only used for problems for which a system of this performance level is absolutely necessary. They must not be used to cover basic or high-performance computing requirements. Access must therefore be controlled in such a way as to ensure proper use of these expensive resources. This task falls to the steering committees of supercomputing centres, set up for this purpose, which will require an increasingly international make-up.

In recent years the HPC landscape in Germany has also become much more organised and structured. The Gauss Centre for Supercomputing unites the three national supercomputing centres in Jülich (JSC), Stuttgart (HLRS) and Garching (LRZ). The Gauss Centre represents Germany in the European project / consortium PRACE and prepares the installation of European supercomputers in Germany. The Gauss Alliance, mentioned previously, brings together selected Tier 2 high-performance computing centres. The Gauss Alliance and the Gauss Centre work together closely to satisfy all requirements relating to the provision of computing capacity, a competitive research infrastructure and training for these top-level systems. The second tier of computer provision, which includes university facilities with regional mandates as well as thematic HPC centres, is especially important to the vitality of the German HPC ecosystem. As centres of competence for the breadth of scientific applications, these facilities create new fields of application and thus serve as incubators for the grand challenges of tomorrow[4]. Given the rapidly increasing complexity of computers and professional programming, HPC training and qualification are extremely important.

4.4 Servers for central basic services

In addition to computing servers, high-performance computers and supercomputers, powerful servers are required to provide basic services and lay the foundation for efficient working in a networked environment. As a result of the growing range of services, the variety of servers is also constantly increasing – with a corresponding range of different functionalities, equipment types, dimensions and special requirements such as failure safeguards. The failure of these servers usually has more dramatic consequences than the failure of a computing server, so high security and high availability are a necessary part of their operation, including installation in separate rooms with restricted access. The subject of data storage is discussed separately in section 4.5. Here we discuss servers in general and then special servers other than computing and data servers.

In terms of operating models, the range of options is expanding all the time. Not every locally required service also needs a locally available server. The question of whether a proposal should include separate server components for specific services, whether a central server should be expanded by including an upgrade or extension in the proposal, or whether the server should be virtualised to provide a centrally delivered service should be examined and decided on a case-by-case basis, with due consideration of the individual circumstances and the IT strategy.

A range of network services which are not originally concerned with scientific tasks is now so fundamental to the functioning of scientific institutions that the centralised provision of services and servers is the most appropriate solution. Examples of these are web services and mail services.

It may be appropriate for several institutions to operate these servers jointly to benefit from synergy effects or to outsource these services. As well as the legal situation (data confidentiality), it is important to consider assurances as to the ongoing development of services, so that universities cannot be forced under the terms of a contract to continue to use technologically obsolete services.

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[4] Position papers of the German Council of Science and Humanities: "Strategic Development of High-Performance Computing and Supercomputing in Germany" (WR-Drs. 1838-12 www.wissenschaftsrat.de/download/archiv/1838-12.pdf) and "Importance and Further Development of Simulation in Research" (WR-Drs. 4032-14 www.wissenschaftsrat.de/download/archiv/4032-14.pdf)

4.5 Storage and archiving systems

4.5.1 General remarks

Collecting scientific data, whether from measurements or computer simulations, is usually associated with a large amount of equipment usage time and work time. This data is often the main source of new scientific insights. New branches of science are emerging that use 'big data', with relevant data volumes on the scale of petabytes which are growing exponentially. Professional data storage and management that allows effective, efficient data exploration is therefore of crucial importance. A large number of established data repositories underline the importance of this issue. For instance, the data repositories developed for the Large Hadron Collider, the sequencing and imaging data from the life sciences, climate research data, and the data from digitisation of image and text sources in the humanities. Accordingly, the efforts of the DFG to provide long-term storage for valuable data from group projects such as Collaborative Research Centres, are in line with these needs.

It is essential that scientific data is stored on suitable servers to bundle the information. A data server should be designed with the features of the data to be stored in mind: security, frequency of access and access characteristics. Means of access include script-enabled command line interfaces and interactive web-based graphic user interfaces. Cloud storage systems offer additional convenient functionalities for data sharing between researchers and support interdisciplinary cooperation. Automatic backup and archiving solutions provided by a high-capacity central facility are often superior to local solutions and also have the advantage that data is stored at another location. The choice of storage technology for data backup must be made as part of a total cost of ownership calculation that includes operating costs (see also section 4.7). In most cases an archive system must also include concepts for long-term archiving (see the next section, 4.5.2). Storage technologies such as Storage Area Networks (SAN) and Network Attached Storage (NAS) have proved their value in this regard and can enhance operational effectiveness. Finally, the question of the replication of data inventories must be considered to allow rapid access from different locations.

A data storage concept also covers disaster planning. As well as the storage of copies at another location, this includes appropriate precautions to cover the time between a total failure and data recovery, for example prompt copying to online storage in addition to data backup with a tape system.

4.5.2 Long-term archiving

Growing digitisation has given rise to new problems in the long-term management of documents and research data, the full extent of which has now become apparent. As well as conventional content such as administrative and legal documentation (certificates, administrative processes, approvals, decisions, expert opinions etc.), research repositories and completely new kinds of archive objects such as 3D-scanned archaeological objects, CAD models and multimedia objects are playing an increasingly important role in the research arena. In the life sciences, for example, the amount of data requiring integration and long-term storage will soon be orders of magnitude larger than current volumes and will demand entirely new concepts for long-term storage and retrieval. The development of error-tolerant and permanent storage systems with capacities above the petabyte range, capable of handling such volumes efficiently, is itself a current area of research which is already being supported by the DFG. It is likely that accelerating advancements in data-generating systems will also result in exponential growth in the amount of data needing to be archived. Rising operating costs for energy and magnetic tape must also be taken into account, as these are no longer a negligible cost factor. Added complexity arises from the fact that even error-free stored data often has to be migrated to new storage technologies after just a few years to keep pace with new technologies and media and keep the data reconstructable and readable. This is especially relevant when data needs to remain retrievable for decades or more to prevent major personal, legal or economic losses. Nowadays old data can often only be evaluated with great effort. Complex standardised data management structures would have to be developed to allow the structure of the stored data to be recovered even many years later, no matter who the individual experiment leader was. The assignment of persistent identifiers to datasets is an important consideration, as is the quality assurance and quality management of the datasets. Finally, long-term data archiving for a period of decades and beyond will require the permanent availability of service staff. Appropriate posts should be created.

4.6 Software

In many IT-relevant areas of research, software now plays a key role. In many cases this means third-party software, which must be acquired and operated as part of the proper operation of the IT infrastructure. A growing proportion of such software can be seen in all IT acquisition proposals. This includes system software, operating software, software tools and user software. Although each individual case will typically have its own characteristics, some procedures should certainly be noted, and these are briefly outlined below.

All possible software alternatives should always be evaluated. On occasion, software monocultures have developed in which a given product is acquired almost automatically without actual practical reasons. In addition, cost comparisons should always include the total costs (acquisition price plus follow-on costs).

The available licence models should also be carefully compared. In different cases, single licences, multiple licences, floating licences, unlimited campus licences or even state licences may be the most cost-effective solution. Some federal states are already working very professionally with state licences, while in others the pattern is still one of purely local procurement decisions. There is still significant savings potential in this regard. Obviously, licence holders must establish transparent and convenient distribution mechanisms, e.g. through web portals.

For software, too, follow-on costs must be taken into account, for example maintenance, updates, licence management or simply the establishment and provision of operating know-how. Here again, there is much to be said in favour of large-scale licence packages. Ultimately, software providers are also obliged to adapt their licence models to the needs of universities and technical developments. Unfortunately, negotiations with licensors who enjoy a monopoly position or where contract extensions involve a considerable amount of work are becoming increasingly problematic. A lack of alternatives places universities in a poor negotiating position. The sustainability of commercial software should therefore be critically examined and noted during long-term planning.

For the licensing of software products for parallel computers, an appropriate number of usable computer nodes must be provided. For example, parallel debugger software typically requires fewer licensed nodes than performance analysis software.

In addition to third-party software, self-developed software is gaining in importance in many branches of research: for example when complex scientific models are formulated algorithmically and realised in the form of software. However, the time and costs involved in developing scientific software are frequently underestimated, especially as this type of software is often very long-lived and may continue to be developed and used for decades. Accordingly, this type of software increasingly represents the scientific essence of research results and in such cases must be regarded as having equal status to traditional scientific quality criteria. The long-term and professional development of such software must however take more account of criteria such as traceability and checkability and permit critical evaluation by the scientific community. These developments are still in the early stages, but given their fundamental importance they should be taken into account now, both in funding proposals and in other contexts.

4.7 Total cost of ownership: an overarching issue

In the operation of computer and storage systems, all costs should always be taken into consideration. As well as the easily ascertained investment costs, the costs involved in the operating phase, in particular electrical power and the staff to operate the system and support its users, should be calculated. For high-performance computers and supercomputers, this is explicitly identified as a future basis for funding in the recommendations of the German Council of Science and Humanities mentioned in section 4.3.

The issue of the energy efficiency of IT products has been brought to the attention of a wider public audience through the popularly used term 'green IT'. Energy efficiency is not only a question of environmental responsibility, but also one of hard-headed economics.

This means that energy consumption factors must be an essential component of IT proposals. The key data of a system – power consumption, electricity consumption for computer operation, electricity consumption for cooling – make up a significant proportion of the operating costs over the anticipated total lifetime of a system and must be included in the evaluation of quotations.

The same applies to staff costs. Complex computer and storage systems cannot be successfully operated in the long term without qualified personnel. The corresponding financial resources for efficient operation must be calculated and made available. It should also be remembered that increasing staff expenditure in certain areas (e.g. for the analysis and optimisation of the energy efficiency of a system) may achieve considerable savings in other areas (in this case, electricity costs). In every case, an economic total cost analysis is desirable.

5 Special Profiles

IT is also playing a growing role in the development of special focus areas and individual profiles at universities. This significance is indicated in general terms in section 2. The following section contains specific recommendations on issues that may not apply at every university but which involve particular features or parameters from an IT perspective which justify a separate description and individual focus. There are further IT-intensive specialisations at universities which do not require separate recommendations. Examples of these might include data-intensive IT applications such as visualisation, robotics or virtualisation.

This section is aimed at CIOs and the managers of relevant facilities.

5.1 IT in scientific high-performance computing (HPC)

Realistic simulations have become established as an essential method of knowledge acquisition in many subject areas. The development of new simulation methods and their professional implementation is often referred to as Computational Science and Engineering (CSE). CSE demands access to high-quality IT infrastructures, because simulation tasks are often some of the most processing-intensive computer applications. CSE is therefore closely linked to high-performance computing (HPC). The development, acquisition and operation of high-performance computers is usually associated with scientific tasks in the field of CSE. Unlike many other IT applications, simulations often require a very close interconnection of system components. This calls for specially designed computer architectures, because many processing-intensive simulation tasks cannot be performed effectively with standard architectures or with cloud or grid services. In the field of scientific HPC and CSE, particular mention should be made of the DFG Priority Programme "Software for Exascale Computing" (SPPEXA) and a call on "Performance Engineering of Scientific Software".

With the aid of computer simulations, theoretical models can be used to make concrete predictions in a way that is not possible with either traditional theory alone or experiments. Climate research is an example of a simulation-based science that has far-reaching political consequences and the potential to trigger radical societal change on a national and global scale. This gives CSE research a significance that has not been sufficiently regarded thus far, because it is often only the predictive quality of simulations that enables scientific results to be used as the basis for economic and social decisions. Conversely, this gives rise to stringent new requirements for the quality and correctness of simulation-basic research, as well as significantly increasing the importance of simulation software. However, the resulting questions are little discussed in the traditional disciplines because the process of change triggered by CSE has not yet been adequately implemented. As a result, the analysis of the opportunities and risks is lagging behind reality. There is a lot of catching-up to do in terms of assuring the sustainability of scientific software; there still is a lack of guidelines and criteria to ensure the reproducibility of simulation results and enable a systematic verification of scientific correctness.

Computer programs that model complex scientific phenomena algorithmically are thus a core outcome of CSE research and ultimately also a research objective of HPC investments. Software must therefore be better recognised as creative scientific work, but conversely, new quality standards must be developed and applied to scientific software, e.g. relating to its sustainability and the reproducibility of results. This is especially true where simulation software is used as the basis for technical, political or societal decisions.

High-quality CSE research is one of the basic prerequisites for the effective use of high-performance computers. Criteria such as the performance and sustainability of software as a core component of simulation-based research should therefore be given more emphasis in the preparation and evaluation of HPC proposals.

On this topic, also refer to the current position paper of the German Council of Science and Humanities entitled "Importance and Further Development of Simulation in Research"[5].

In view of advances in CSE and HPC, these topics should also be better embedded in university education. Necessary measures include the provision of special, focused compact courses for HPC users, the provision of advanced classes in simulation technology and HPC for students in traditional subjects, and the design of new interdisciplinary courses in CSE.

5.2 IT in university medicine

Information technology is of relevance to a growing number of work processes in medical research and healthcare provision and has resulted in a gradual transformation of the entire healthcare system towards new and often redesigned processes. This applies not only to traditional data and information management but also to all diagnosis, treatment and logistics processes which can be technology-supported as well as a new generation of decision support and knowledge management systems, which in turn have a major influence on the training of doctors and other healthcare professionals. Increasingly, the efficiency of these information infrastructures is a decisive success factor in patient care, research and teaching at university hospitals, particularly in terms of international competition.

5.2.1 IT-related challenge

There is a significant need for the integration of new medical data from omics laboratories and data from a wide range of sensor applications, whether through patients or as part of medical diagnostics (big data).

The integration of medical and laboratory technology with patient-centred treatment support is still moving on.

Linking in to Germany's e-health infrastructure: As a result of the German E-health Act, it is likely that in years to come, all university hospitals will have to expand their cooperation with other healthcare provision institutions in Germany and adapt their existing IT installations. It

[5] WR-Drs. 4032-14 www.wissenschaftsrat.de/download/archiv/4032-14.pdf

follows that inter-institutional Electronic Patient Records (EPRs) play a crucial role in the bundling of isolated processes in healthcare telematics and form the basis of a healthcare telematics infrastructure. Consideration should also be given to growing patient demands to be able to view the data stored in an EPR and be able to control access authorisation and import/export data. New forms of cooperative treatment will emerge, which, based on EPRs and telemedical processes, will lead to the integration of other services such as mobile patient care, residential homes of all types, emergency services and caring communities. These data repositories will also represent an important source of data for knowledge management (see above), phenotype-oriented research and healthcare provision research.

New data producers: Today, clinical IT landscapes are characterised by traditional IT systems for patient care and the IT structures and volumes of data that these systems require. In years to come many processes will come into use in university medicine that will significantly exceed these data volumes. These include extremely data-intensive lab procedures in molecular diagnostics (NGS, omics), new medical sensor technology to measure almost any body function, new diagnostic imaging procedures and the digitisation of pathology. Scientifically utilised image archives will also become more important.

Lab procedures – including the often associated biobank systems – demand highly industrialised work processes and data processing in order to supply quality-assured data in line with standardised rules. As in all areas of research and healthcare provision, the documentation of the quality of methods used through metadata will play a more important role than in the past.

Design of IT structures for knowledge management and translation: There will be a growing focus on the integration and use of existing data to generate knowledge and/or support decision-making in patient care, but more especially in research. The main purposes of this are to provide access to what is mostly traditionally unstructured knowledge in clinical and inter-institutional information systems and establish close links with data repositories in omics, clinical registers and data collections, medical technology systems, central biomaterial banks and image data, as well as external knowledge in libraries and public databases.

This calls for an IT infrastructure composed of various components that will form a central pillar of the complete IT architecture of university medicine. Translation processes that convey well characterised data between clinical practice and research are required in all areas. These rely on strict, transparent quality and metadata management to enable reproducible and statistically valid evaluations to be performed. At university hospitals this calls for a professionalisation and standardisation of information infrastructures in medical research – as envisaged in the INF projects of the Collaborative Research Centres (CRCs), for example. At the core of this central pillar will be a data warehouse containing the data and metadata earmarked for further use.

Between now and 2020, IT infrastructures for the nationwide integration of research data will also acquire strategic importance. In these processes, too, the use of classification systems and internationally established terminologies (e.g. SNOMED, Loinc, IHE and RDA; see below) will be essential.

The management of this highly networked research data, including increasingly complex rights management, will acquire a scope for which university hospitals will have to develop dedicated infrastructure groups with substantial resources in order to keep pace with international developments, e.g. research geared towards personalised medicine.

IT and medical devices: As it becomes ever more necessary to integrate medical devices and IT systems, university hospitals face two main challenges: (1) network integration and (2) data / system integration. The network integration of medical devices often results in considerable risks, as they often fail to comply fully with current security standards and it is therefore impossible to achieve endpoint security. This must be compensated for by means of gateways with a wide range of network partitions.

Today, system integration often demands partially or fully proprietary integration concepts. It is likely that international standards (especially IHE) will become increasingly common in this regard. These must interact with the above-mentioned gateways, giving rise to high-complexity solutions that imply a significantly greater need for support.

Increased use of classification systems: Both internationally established terminologies (e.g. SNOMED, Loinc) and international standards such as IHE or RDA must be made available. It will be necessary to use these components / standards, which have so far been neglected in Germany, more consistently. In clinical research groups, highly networked research data and the processes in which it is generated, including increasingly complex rights management, will acquire a scope for which university hospitals will have to develop dedicated infrastructure groups with substantial resources in order to keep pace with internationally emerging forms of research geared towards personalised medicine. This also calls for the structuring of knowledge in line with the above-named systems, e.g. SNOMED.

Modernisation of the use of media in teaching: Forms of teaching based on digital materials will be used more and more in medical faculties, and this will require considerable resources. In particular, there is a need for long-term planning which must be closely linked to the development of medical studies (reform curricula). The growing personalisation of medicine and the associated rapid growth of new clinically relevant knowledge will make new teaching objectives, methods and labs necessary. Medical students must be prepared for the transformation of their future profession by IT; in their knowledge-based profession they will employ a range of supporting systems which they must be able to use critically (knowledge presentation, decision management, long-term documentation, patient participation).

5.2.2 Requirements for university hospitals

To successfully counter the challenges outlined, three main success factors may be named, which are closely interconnected and must be coordinated in planning documents. They reflect corporate strategy:

1. Overall IT architecture and interoperability of components
2. IT organisation and services
3. Long-term availability of resources

It is likely that the IT landscapes in existence today will have to be integrated with the new areas outlined above. This gives vital importance to the overall architecture of the IT landscape and standardised interoperability. It is also likely that it will become all but impossible to continue connecting and managing heterogeneous, fairly non-standardised IT landscapes. One of the main objectives of an overall architecture should therefore be to create system blocks which are as homogeneous as possible with external interfaces based on open, internationally established interoperability standards; the IHE initiative would appear to be the most promising choice for grouping and responding to the various requirements.

The implementation of such an architecture will place particular demands on the IT organisation. Strategic IT planning for university medicine is becoming a core element of overall planning. It develops an importance and a complexity that cannot be easily managed because it must link the corporate strategy and its dynamism to the dynamism of technical development.

The DFG recommendations for "Integrated Information Management"[6] must be updated and implemented with reference to the specified conditions: Information infrastructures must be re-examined across the whole campus and nationwide in terms of data centre operation and the storage / archiving of big data. This means that the uncoordinated coexistence of responsibilities, capacities and staff that can be found at most institutions should be reformed between now and 2020 – otherwise, it might no longer be possible to finance IT solutions for university medicine, not to mention the considerable catching-up to be done compared with other countries. The changes addressed here are part of the process of transformation in medicine brought about by IT and require a large number of extremely well trained medical IT staff.

Special requirements in the clinical domain: It is difficult to anticipate new requirements in the clinical domain; the linking of tertiary and primary forms of care – for example the integration of care for rare diseases between the outpatient clinics of high-performance medicine and local physicians or assistant roles. New forms of cooperative treatment will emerge on the basis of EPRs or with the use of telemedicine. It is especially difficult to make a realistic assessment of the security requirement for sensitive personal data, high-security areas of research and life-critical infrastructure components. However, this aspect must be addressed in strategic planning for university hospitals. The information and guidelines now available must be followed.

Regardless of the IT approach used, the ethical, legal and social aspects (ELSA) must be taken into consideration. In terms of ELSA, the primary focus should be on the growing importance of the 'caring community' (see the federal government's demographic strategy) and supporting the right and ability of patients to make choices, as is already expressed in the German Patients' Rights Act. The new information infrastructures will have to be developed in parallel to and in addition to current ones, which means that additional resources in the form of staff and investments will be needed.

5.2.3 Requirements for advisory reviews

The transformation of medicine described here is already in full swing and is only being delayed by the underfunding of this sector (see section 7.6). Given the complexity and size of the likely acquisition and change processes, the DFG can only provide adequate advisory support if

[6] www.dfg.de/dfg_profil/gremien/hauptausschuss/it_infrastruktur/best_practice_workshop/index.html

applicants can present very well structured and strategically oriented documents. The scope and nature of individual IT acquisitions can only be estimated with reference to the full background.

The information provided must include concepts for the overall architecture as an outcome of corporate planning and a description of the interoperability of the systems; the strategy of cross-location networking for both patient care and research must be taken into account. The planned IT organisation and provision of resources must also be outlined. Questions as complex and far-reaching as this will mostly require on-site reviews.

The review of routine components in medical and information technology, however, can usually take place in writing and within a short time-frame.

In all other respects, the information and procedures outlined in the other sections of these recommendations apply to university hospitals.

6 Funding Considerations / Funding Strategy

As has been shown in the previous sections, IT permeates virtually all areas of higher education and research. Some aspects require special consideration beyond the university level and have a higher-level significance.

This section aims at funding providers, especially at federal government and federal state level, and provides recommendations on the positioning of IT in funding programmes, regional IT concepts and the design and further development of funding programmes.

Consultations on these recommendations also raised a number of points which will be of great importance in future funding. These can be divided into general and basic strategic aspects.

6.1 General recommendations

- Funding should contribute to the formation of structures at national and/or international level.
- State concepts for entire regions promote the effective use of resources.
- Funding measures are strengthened by reviews and progress evaluations.
- Emphasis is given to data management with long-term quality-focused curation.
- Concepts of “open science” must be addressed and distinguished.
- Data-rich projects should be accompanied by concrete evaluation strategies.
- New methods of measurement and analysis may give rise to new ethical, legal and social aspects (ELSA).

6.2 Basic strategic aspects

Measuring techniques, data management and evaluation are becoming more and more deeply integrated. They must increasingly be viewed in context. The traditional boundaries not only of scientific institutions but also of work processes are changing. As a result, the acquisition of hardware can only be evaluated in the context of the available software and associated scientific services. Hardware acquisitions without suitable evidence of usage options can no longer be justified given the shortage of funding for information infrastructures. This has significant impacts on announcements for funding programmes too.

The restriction of funding to investments, in the current definition of major instrumentation, no longer seems appropriate, or indeed would even seem to encourage inefficiency. Increasingly, integrated examinations and funding opportunities for instrumentation and services are needed.

The information infrastructure as a whole must be reviewed, not just isolated IT components. This is only possible in the context of strategy papers that enable the clear, efficient orientation of infrastructure in line with requirement profiles and defined processes. Increasingly, this must take place against the background of information infrastructures that extend beyond the boundaries of individual institutions.

The greatest risk of poor investments results from funding mechanisms that continue to take place within a project view created for research projects in previous decades. Infrastructure management initially has project character, but over the course of several years changes to a primarily long-term consideration of service processes which will grow significantly in view of the growing number of tasks in data curation. New funding strategies must therefore be developed that guarantee sustainability and high performance on the one hand and allow for competition as a driving force of development on the other.

Accordingly, the use of data und stored research materials require Use and Access Committees – a model already established in international collaborative research. Furthermore, the use of IT infrastructure resources should be subject to governance models at the respective institutions. This is the only way to represent the very different interests of methodologically different research approaches and to establish a climate of trust with regard to the use of substantial financial resources in infrastructure centres. In this way, the interests of sophisticated long-term projects and massive big data projects can be transparently reconciled.

7 Funding Opportunities

IT investments for universities and university hospitals are funded by the federal government and the federal states. They are mainly applied for through three open programmes, which are described below from an IT perspective[7]. There are also special and third-party funding programmes. Proposals should be embedded in the IT concepts developed at university level and possibly at regional level (see sections 2.3 and 6.1).

7.1 Major Research Instrumentation

The Major Research Instrumentation programme as defined in Art. 91b of the German Basic Law is of interest for IT systems used predominantly for research. This is typically the case for Tier 3 high-performance computers and dedicated computer clusters. Purely storage-related proposals can only be regarded as major research instrumentation in special circumstances. Evidence must be provided of direct use in research projects, for example for simulations or the processing of significant amounts of data. In the event of a positive decision, the DFG will finance 50% of the investment costs (assuming that the federal state undertakes to cover the other 50% from state funds).

The average total annual investment volume for IT investments is €16 million, based on an average of 25 proposals.

7.2 Major Instrumentation in Research Buildings

Major research instrumentation involving investment costs of over €5 million may be applied for through the research buildings programme. In the area of IT, this affects Tier 2 high-performance computers and supercomputers. The DFG is involved in the review of proposals prior to a decision by the German Council of Science and Humanities and issues recommendations.

The same programme also covers research buildings in which instrumentation investments may be planned. Following a positive decision, proposals for instrumentation are normally presented to the DFG for review and evaluation before construction is complete. As with the Major Research Instrumentation programme, this may involve IT systems. During the review process appropriate criteria are applied and the DFG then issues recommendations.

Between 2007 and 2014, a total of 19 IT proposals were recommended with investment costs of €124 million.

[7] A detailed description of the programmes as well as guidelines and proposal forms are available at www.dfg.de/en/wgi

7.3 State Funded Major Instrumentation (Großgeräte der Länder)

The State Funded Major Instrumentation programme is a very relevant funding programme for IT investments. Proposals may also be submitted for IT systems as part of basic provision. Typical examples include backup / storage systems, library or hospital IT systems (hospital information systems, clinical workstation systems, subsystems). However, it is also possible to submit proposals for (state-wide) software licences, e-Learning platforms or general administrative IT. Finally, the programme allows applicants to request funding for special IT systems: Researcher Personal Computers (WAP) and proposals for networking components.

The extent to which proposal opportunities can be used should be clarified with the relevant ministries within the state governments. The DFG reviews and evaluates submitted proposals – including the university IT concepts submitted along with them if requested – and issues recommendations.

Each year, recommendations are issued for an average of over €40 million in IT investments (with approximately 70 proposals per year).

A detailed analysis of proposal figures was carried out in 2012 based on the first five years following the introduction of the programmes[8]. The report containing the published results also provides information about the proportion of IT proposals. Another detailed evaluation of proposal figures is planned. In the period from 2007 to 2014, IT-related investments amounting to a total of €494 million were reviewed and recommended by the DFG within the framework of these programmes.

7.4 Special funding

Tier 1 supercomputers are funded through separate programmes with the participation of the federal states in which the equipment is based and the federal government. Some Tier 2 centres in the non-university domain also receive special funding.

The German Council of Science and Humanities has adopted a set of recommendations for the funding of National High-Performance Computing and Supercomputing in Germany[9], the implementation of which is currently being discussed by the federal and state governments. These may have far-reaching consequences for the funding of Tier 1 and Tier 2 systems.

7.5 Third-party funding

In addition to the above-mentioned programmes for major instrumentation at universities, third-party funding providers also offer funding opportunities for IT equipment. The criteria are defined by the individual funding agency. The criteria applied by the DFG serve as an example.

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[8] www.dfg.de/download/pdf/foerderung/programme/wgi/fuenf_jahre_grossgeraeteprogramme.pdf

[9] WR-Drs. 4488-15 www.wissenschaftsrat.de/download/archiv/4488-15.pdf

In order to be approved, the project-specific necessity of the instrumentation must be explained in the proposal. The proposal must also be for so-called additional support. Instrumentation that can be regarded as part of an institution's basic instrumentation infrastructure cannot be funded. In practice, this reduces the proposal opportunities for IT instrumentation to dedicated additional equipment where basic equipment can be demonstrated to exist. Between 2007 and 2014, the DFG approved a total of €70 million in project funding for IT-related investments. The question of basic equipment also affects funding applications for standard software. Moreover, DFG funds cannot be used to cover the utilisation of data centres.

IT equipment financed through third-party funding, especially if it exceeds a certain size[10], must be integrated in the IT concept of a university and its procurement and operation must be coordinated.

7.6 Evaluation of funding opportunities

Investments in research infrastructure are possible through programmes financed by the federal and state governments. Through the DFG review process, such measures undergo quality assurance in accordance with national scientific and technical standards. Particularly in the case of complex IT systems, the peer review process frequently incorporates an advisory element in the form of comments arising from the review. The DFG emphatically calls for an increased investment volume, especially for the State Funded Major Instrumentation programme, and for proposal opportunities to be fully utilised. Particularly in medicine, underfunding can be observed in the area of IT investment. At the same time, the demand for (national) IT / data platforms is growing. This was recently expressed in recommendations issued by the Senate Commission on Key Questions in Clinical Research[11], which call for the increased use of opportunities such as State Funded Major Instrumentation programme for such IT systems.

Apart from the actual investments, operating costs account for a growing proportion of total costs. These are normally covered by the supporting institutions. With regard to HPC, the possibility has been raised through the recommendations of the German Council of Science and Humanities of the total costs being shared by the federal and state governments. This is greatly welcomed by the DFG.

In IT the boundaries of traditional investments are occasionally blurred, for example in the context of cloud services or software. The federal and state governments are called on to take account of the changing framework affecting IT solutions in the ongoing development of funding programmes. This may be necessary for regional concepts where the provision and usage of services take place in different locations. Funding routes should be installed for the use of services, in order to avoid a situation where the (currently available) option of applying for in-

[10] This should generally apply as of a funding volume of €100 000 or more.

[11] www.dfg.de/download/pdf/dfg_im_profil/reden_stellungnahmen/2015/sgkf_empfehlungen_klinische_forschung_150720.pdf

house investments is perceived as the easier route, potentially hampering more efficient usage models.