Summary

When anaesthetists make decisions, these are based on patient information, on knowledge, and on experience. The amount of information grows explosively, due to developments in micro-electronics, which permit measurement of more variables with a higher precision. In addition to the amount of information, the amount of knowledge that a physician needs to make decisions, increases rapidly. The knowledge has to be broader because the variety of information increases. The knowledge must be deeper, because the insight in physiological mechanisms increases and consequently, the number of therapeutic possibilities. The amount of knowledge does not only increase, but insights also change. To keep his/her knowledge up-to-date, a physician can consult an experienced colleague, or study literature.

The amount of patient information and of medical knowledge is becoming so large that physicians are forced to make selections. Knowledge and experience play an important role in the selection process. To select information, knowledge is required of the importance of information as an indicator of the condition of the patient. To select literature, knowledge is required of literature search systems and insight is needed into the importance of different articles.

In chapter 2 it is described how computers can be used to support physicians. A distinction is made between information management and decision support. For information management many applications have been realized. For decision support few systems that are applicable in daily practice have been realized. Reasons are that it is not known exactly how a physician makes decisions, how he or she uses information, recognizes patterns, and selects characteristic signs.

In the sequel of chapter 2, the situation of the anaesthetist in the operating theatre is discussed. A survey is given of Carola, an information management system that has been developed for cardiopulmonary anaesthesia in the University Hospital Groningen. Carola documents data of open-heart procedures automatically, presents them in the operating theatre and stores the data in a database. To make the database accessible for research, a query language has been developed, suited to process time-dependent data.

In chapter 3, methods and techniques from Artificial Intelligence that are relevant to provide decision support in Anaesthesia are discussed. Attention is focused on diagnosis. The way in which man infers a diagnosis, can be modelled as a generate-and-test procedure: possible solutions for a problem are generated, and subsequently for each solution it is tested whether it is a right one.

To generate-and-test diagnoses on a computer, the knowledge that humans use for this task must be formalized and stored in a knowledge base. The knowledge required
for diagnosis can be represented with three relational concepts: Hassign, Caus, and Isa. Hassign relations represent the signs of a disease. Caus relations represent cause-effect relationships between physiological events. Isa relations represent the relation between diseases or physiological events, and their subcategories. Knowledge represented with the concepts Hassign, Caus and Isa permits categorical reasoning. Categorical diagnostic reasoning results in a differential diagnosis, consisting of possible diagnostic hypotheses.

In Artificial Intelligence, besides methods for categorical reasoning, also methods for plausible reasoning have been developed. They permit ordering of hypotheses according to some plausibility measure, e.g., probability. Such an ordering can be used either to force a decision or to guide the acquisition of additional information. Forcing a decision means that the diagnostic hypothesis with the highest plausibility is adopted as the single right answer. In information acquisition, the ordering can be used to maximize the probability that, after acquisition of additional information, only one diagnosis remains possible. The most widely known methods for plausible reasoning have been evaluated: Bayesian statistics, the Certainty Factor model, the Dempster-Shafer theory of evidence and Fuzzy Logic. For the formulas used in Bayesian statistics to combine information, it can be proven that they are correct, since they are based on the notion of probability, the meaning of which is unambiguously postulated. For the formulas of other methods to combine information it can not be proven that they are correct. Advantages of Fuzzy Logic over the Certainty Factor model and the Dempster-Shafer theory are, that the way in which information is combined, is more clear to the user, and that it is possible to represent knowledge about interactions. Bayesian statistics supports a rational approach of decision making while Fuzzy Logic supports a normative approach. It seems that both approaches are used next to each other in the field of health care.

In chapter 4 a distinction is made between chronic care and acute care. Anaesthesia during surgery mainly concerns acute care. In acute care an 'information driven' strategy is followed. The condition of the patient is monitored continuously with equipment. The information from the equipment is used to detect critical events that can occur any time. In chronic care, a 'diagnosis driven' strategy is followed. In the diagnostic process it is determined which information is required to infer a diagnosis that is as accurate as possible. Time constraints are not important in general.

Acute care during surgery is twofold: conditions have to be established in which the operation can take place; on the other hand, the damage caused by the intervention must be kept to a minimum. Initially, the anaesthetist bases his policy on the type of operation, the anaesthetic technique used and the patient. The policy is adapted to a specific patient on the basis of age, sex, pre-operative medication and other patient-specific information. Information that becomes available during the operation can lead to adaptation of the policy followed.

The term Patient Specific Model is used as an abstraction of the view the anaesthetist has of the patient. In chapter 4, this model is used as a basis for specification of a decision support system. The knowledge required by the system to construct an internal Patient Specific Model is represented in a number of submodels. One of these is the Physiological Model, which describes the relations between different variables important to monitor the condition of the patient. Furthermore, submodels describing anaesthesia.
techniques, types of operation and the effects of drugs are required. With information
that becomes available during the operation, the knowledge in the submodels is made
patient-specific. To maintain a clear distinction between the actual view of the patient and
the information from which this picture has been constructed, the information of patient
and operation is stored in a local operation database.

A first level of support that can be provided, is validation of and event-detection in
the information collected during the operation. Another possibility is the provision of
support requested by the anaesthetist. A planned intervention, for example, may first be
simulated on the computer, to see whether it conflicts with the actual condition of the
patient. Also, the effect of the intervention on particular variables can be simulated to
check whether the intended effect actually occurs.

The conceptual structure for a decision support system must then be implemented on a
computer. The knowledge in the different models must be represented; it must be possible
to combine quantitative and qualitative knowledge. Part of the physiological knowledge
that is used during operations is quantitative. The interpretation by the anaesthetist
however is mainly qualitative. Quantitative modelling of physiological processes requires
modelling-techniques that are complex, since physiological processes are dynamic and
non-linear. These techniques impose constraints that can not be fulfilled in practice. In
the operating theatre, a limited number of, sometimes derived, variables is measured such
that a purely formal approach is insufficient. The constraints can only be determined
heuristically.

The required quantitative and qualitative knowledge in the models and heuristics
can be represented as relations. A language based on the relational formalism is RL.
With RL, quantitative and qualitative relations can be combined. RL/1 is a prototype
implementation of RL. In RL/1 a simple physiological model has been represented. With
this model it has been demonstrated that different support functions can be realized on
the basis of a single model.

Chapter 5 discusses constraint satisfaction. Constraints are relations that must be
satisfied. Constraints apply to variables that can have values from particular domains.
A constraint satisfaction system chooses values from the domains associated with the
variables such that the relations are satisfied; this is designated as solving of the constraints.
Declarative formulation of problems with constraints and solving the constraints with a
constraint satisfaction system has advantages over direct formulation of a procedure to
solve the problem. Firstly, the problem can be modified easily by addition or deletion
of constraints. Secondly, a declaratively represented problem is usually more clear to
man. On the other hand, a disadvantage of constraints is that the time required to solve a
problem increases disproportionally with the size of the problem — often exponentially.
Furthermore, the set of constraints in which a problem is formulated may be inconsistent
and by consequence unsolvable. The inconsistency can be resolved by dropping a number
of constraints. To make it possible for a constraint satisfaction system to decide by itself
which constraints are to be dropped, priorities can be assigned to constraints; a prioritized
set of constraints is designated as a constraint hierarchy.

A number of methods and systems for satisfaction of constraint problems are dis-
cussed. A well known system for constraint satisfaction is Prolog. However, Prolog
can only solve constraints related to variables with finite domains, whereas physiological variables have infinite domains. Constraints applying to these variables are algebraic. Algebraic constraints can be solved by the constraint satisfaction systems Thinglab and RL/1. For Thinglab, a modification is proposed to increase its efficiency. For RL/1, an extension is proposed to solve constraint-hierarchies instead of sets of constraints of equal priority.

In chapter 6 validation of information with a computer is discussed. The validity of information determines what conclusions can be inferred and how correct the conclusions are. A human observer filters incorrect information and bases conclusions on the remaining information. Also, conclusions can be inferred that are based on incomplete or partially correct information. Incorrect information is distracting and can be dangerous, when it implies wrong conclusions. Therefore, data validation is an important component of information management.

When information is interpreted by a computer, incorrect information in the best case results in inconsistencies that distract the attention of the anaesthetist. When no inconsistencies occur, incorrect conclusions might be inferred by the system. When the anaesthetist recognizes an incorrect conclusion, his confidence in the system decreases; otherwise, it is incorrect information. Thus, validation is even more important for decision support than for information management.

For anaesthesia it has been investigated which artifacts occur in measurement data and which errors are made in manual data entry. It was found that, apart from incorrectness, primarily incompleteness of the data is a problem. In manual entry, the user interface in the operation theatre determines the nature of errors and missing information. A validation process is described which can be built into Carola and examples of online information validation are given. Validation must also be applied when data are obtained from the Carola database.

A third application of data validation is between different databases for data related to the operation. Communication must be possible between the databases, and it must be possible to identify data. When data are stored in both databases, redundancy permits validation. When data are completed from another database, consistency with the data that are already present can be checked. When inconsistencies occur, it must be determined where they occur, and corrections must be made at the right locations.

Chapter 7 describes the use of value-intervals within the generate-and-test procedure for diagnosis. With intervals, uncertainty about values of variables can be expressed, and qualitative and quantitative reasoning can be linked. The value of a variable is never known with certainty, not even when it is measured. The measured value for a variable needs not to be equal to its true value. The true value resides in an interval surrounding the measured value; the length of the interval is a function of the accuracy of the measurement. When a variable can not be measured, it can only be asserted that its value is restricted to its physiological range, which is also an interval.

A constraint satisfaction system has been implemented which exploits algebraic equations to combine intervals that have been assigned to variables based on measurements. By combining intervals for different variables, the intervals for individual variables may become smaller. The constraint-satisfaction system can also infer that the intervals input
to the constraint satisfaction are inconsistent according to the equations that must hold between the variables associated with the intervals.

Within the generate-and-test procedure, the constraint satisfaction system can both be used in the generation phase and in the test phase. As described above, the intervals in which the values of variables must reside can be made smaller by the constraint satisfaction system. Next, the intervals are translated into qualitative values such as 'increased', 'normal' and 'decreased'. When the value of a variable is 'increased' or 'decreased', this is a symptom which must be explained by the diagnosis to be inferred. Using qualitative knowledge (represented in Has, Caus and Isa relations), diagnostic hypotheses are generated that explain the observed symptoms; the observed symptoms are a subset of the symptoms that are to be expected with the diagnostic hypotheses. The generated hypotheses are tested by checking whether, apart from the observed symptoms, also the other symptoms that are to be expected with a hypothesis conform to what has been measured on the patient. Signs that consist of an abnormal value for a variable (the qualitative value is 'high' or 'low') are translated into intervals and subsequently the constraint satisfaction system is used to test whether the resulting intervals are consistent with each other and with the intervals that have been determined during the generation phase, according to the equations that must hold between the variables. When the intervals are inconsistent the considered diagnostic hypothesis is rejected. Using this version of the generate-and-test method it could be concluded for an example set of measurement data that a high heart frequency and a low systemic vascular resistance were symptoms and that the only possible diagnosis explaining these symptoms was shock.

In general, it can be concluded that modelling of quantitative and algebraic knowledge can make an important contribution to decision support in Anaesthesia.