More Than the Sum of Its Parts

Today many technical systems are equipped with multiple sensors and information sources, like cameras, ultrasound sensors or web databases. It is no problem to generate an exorbitantly large amount of data, but it is mostly unsolved how to take advantage of the expectation that the collected data provide more information than the sum of its parts. The design and analysis of algorithms for sensor data and information acquisition and fusion as well as the usage in a differentiated application field was the major focus of the Seminar held in the International Conference and Research Center (IBFI), Schloss Dagstuhl. 24 researchers, practitioners, and application experts from different areas met to summarize the current state-of-the-art technology in data and information fusion, to discuss current research problems in fusion, and to envision future demands of this challenging research field. The considered application scenarios for data and information fusion were in the fields of computer vision and medicine.

Applications of Sensor Data and Information Fusion

Computer Vision

The research field of computer vision deals with the problem of designing algorithms and building systems that gain information from images or multidimensional data. Typical examples are the tracking objects, the estimation of 3-D structure and motion, the recognition of objects or the analysis of complex scenes. In the seminar we studied two major tasks of fusion:

1. Strategies for the acquisition of images and data to solve individual computer vision tasks in an optimal manner, and
2. Efficient algorithms for image data and information fusion to solve computer vision and robotics problems reliably.

The fusion of statistical information extracted from images is applied to object tracking, multiple views and viewpoint planning to support active object recognition with robots. Multimodal sensor data allow for the implementation of an attention system for robots and advanced driver assistance systems rely on sensor data fusion.

Driver assistance systems, for instance, provide options like lane departure warning adaptive cruise control units. Multiple sensors are required to collect all the data to perceive the environment around the car. The fusion algorithms for this specific application underlay important constraints: It has to guarantee the demanded high degree of reliability and to fulfill the strong cost requirements of the automobile industry.

2.2 Medicine

Medical imaging is an emerging field which has experienced recently a tremendous reduction of innovation cycles. Progress and advances in medical imaging have an immediate impact on commercial products and clinical practice. Today various imaging modalities with completely different capabilities are available for diagnosis, intervention, surgery, or monitoring. Each modality like X-ray, computerized tomography, magnetic resonance imaging or ultrasound has its own advantage. In multi-modal image registration, images of different modalities are transformed into a single coordinate system such that an overlay fading of the images is possible. Physicians get simultaneous access to the patient’s image data and no mental combination of various information sources is required anymore. Today industry provides combined, i.e. hybrid systems like SPECT/CT-, PET/CT-, or PET/MR-scanners to allow for the registration of functional and morphologic images. Software-based image registration is still considered unsolved and is an important basic research task in the field of medical image processing. The mathematical modeling and judgment of non-rigid deformations, the definition of proper similarity measures between images acquired by different modalities, the treatment of different image dimensions and the incorporation of prior knowledge are considered to be the major scientific challenges.

3 Methods

Image registration and data fusion can be considered as an optimization task: a proper objective function is defined, and the the fusion task is solved by the optimization of the objective function. This includes both classification and regression problems.

In image registration, for instance, the objective function is defined through distances of assigned image intensities or matched point features. Within the
optimization process the transformation parameters are estimated that mini-
mize the objective function. The registration problem based on point correspon-
dences can be considered as a mixed integer optimization problem. Intensity
based image registration requires the optimization of an objective function that
measures the similarity of intensities of assigned image grid points. Commonly
variational approaches are used as well as gradient descent methods. In the se-
minar it was also shown that the variational formulation can be interpreted in
the context of optimal control of partial differential equations. Other contribu-
tions have demonstrated that registration can be done in an unified framework
with image pre-processing like intensity correction, image enhancement, and seg-
mentation. Prior knowledge for image registration can be generated by hybrid
scanners or manually registered data sets. By the incorporation of specific statisti-
cally motivated regularization terms, the objective function can take account
for priors. The diagnosis of incomplete multimodal image data makes use of
priors, too. In the seminar novel statistical learning methods for the analysis
incomplete data as well as for the acquisition of priors were discussed.

Statistical approaches contribute to advances in decision making and clas-
sification in the presence of multiple information sources. The Bayesian theory
of designing multiple expert systems provides a formalism for the treatment of
sensor data fusion in pattern recognition and opens up new dimensions in classi-
fication theory. This technology can be applied to standard pattern recognition
problems as well as applications like driver assistance, object tracking or robot
attention control.

4 Conclusions

Computer vision problems are traditionally motivated by robotics and surveil-
lance applications. Most medical image analysis problems come from the appli-
cation fields medicine and biology. Though no less important, the information
fusion problems posed by the robotics community tend to be more related to
basic research than those arising from medicine. As they are typically dynamic
in nature, must work quickly, and must effectively deal with rapidly changing
and unknown environments. By comparison, the majority of information fusion
problems in medicine and biology are static and operate under more control-
led conditions. Not surprisingly, techniques to perform information fusion have
evolved differently in these communities with minor to no overlap.

In an inspiring environment the seminar brought together members of both
communities and initialized scientific discussions that yield hope for the huge
potential of synergies.