Relationships between Image Synthesis and Analysis: towards unification?

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Abstract.

Image analysis and image synthesis have evolved on separate tracks, at different paces. There is however an increasing awareness of the numerous and growing overlaps between the two fields. By detailing the various areas where such overlaps might be found, this report wishes to promote unification of analysis and synthesis into “imagery”.

Three ways of looking for common ground are presented: common *theoretical background*, common *areas of study*, and common *applications*. They show that the distinction between image synthesis and image analysis has outlived its usefulness. The absolute differences can be discarded; what remains is a great commonality of interest.

1. Introduction.

This report attempts to bridge some gaps between the image analysis and image synthesis communities. It reflects ideas from people working in both domains, and will be used as a start-up document for the Eurographics working group on relationships between image analysis and synthesis. Both disciplines have a fairly eclectic nature: for example, image analysis borrows freely from artificial intelligence and psychophysics, while image synthesis includes much from the field of human-computer interaction. This characteristic means that introducing further extensions accords with the spirit of research in both fields.

The present discussion also has the more ambitious aim of providing some pointers to a solution to the obvious pitfall of eclecticism: the lack of a coherent basis to underpin the fields. In this sense we are trying to contribute to a *final* extension to both fields.

1.1 Definitions.

In what follows, an *image* is considered to be a function $(x,y) \rightarrow I(x,y)$, where (x,y) are coordinates on a two-dimensional grid, and where I is a measure such as brightness. In a more general manner, images can be characterized by a support of dimension higher than two, as is the case with a sequence of images $I(x,y,t)$. Or, for a given grid, there can also be more than

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one measure at each location; this is what happens when spectral information is taken into account: I(x,y,λ). This spectral information is usually reduced to a triple {$I_{red}(x,y)$, $I_{green}(x,y)$, $I_{blue}(x,y)$}. In all these situations, the basic structure of information is an array of quantized numerical values, the basic element of information being a pixel, or *picture element*.

1.1.1 Image synthesis.

Image synthesis consists in determining a value for each of these pixels, the end product being an image with (hopefully) some semantic and/or artistic content. Image synthesis has always been closely associated with human-computer interaction. Most standard texts describe interactive computer graphics and not just image synthesis *per se*. The ability to change pixels rapidly leads naturally to interactive generation of static and dynamic pictures. The full exploitation of the computer as a medium for image synthesis is thus only achieved in a dynamic, interactive environment. In the remainder of this discussion we shall use the term *image synthesis* to encompass all these aspects.

If we neglect the complexities of interaction, synthesizing an image involves, very roughly, the following:

- modelling three-dimensional objects, i.e., describing their morphology, attributes, and sometimes functionality;
- composing a scene by instancing these objects at various locations within a common reference frame;
- lighting the scene, which involves modelling light sources and illumination mechanisms;
- determining the reflection and shading effects of these sources on object surfaces;
- removing invisible areas of the scene and projecting visible parts onto I(x,y);
- displaying I(x,y), which means taking into account display as well as human visual system characteristics.

Concepts from many computing disciplines are used, from data base handling to software engineering. So what is (or is not) image synthesis? For simplicity, image synthesis is assumed to be implicitly defined by the above or by what appears in the numerous references, such as [New81] [Fol82] [Har83] [Rog85] [Mag87] [Sal87] [Burg89] [Ger89] [Eurographics] [Siggraph].

1.1.2 Image analysis.

Rather than trying to determine I(x,y) for each pixel, image analysis starts with image(s) for which each pixel has a known value. It is customary to subdivide the domain into *image processing*, *image analysis stricto sensu*, and *computer vision**. Image processing consists in transforming one image into another image, often with the same support; the purpose is typically to eliminate or enhance some features [Pra78] [Cas79] [Hal79]. Image analysis goes one step further by extracting parameters and analysing them [Dud73] [Ros82] [Han86] [Gon87]; classical examples can be found in medical imaging or industrial robotics [CVGIP] [CVPR] [Eusipco] [SignalProc]. The steps are typically:

- image acquisition, i.e., from the sensor to I(x,y);

- preprocessing (enhancement), for example noise reduction by filtering;
- segmentation of the image into its constitutive parts, such as regions and edges;
- parameter extraction;
- classification, for identifying the elements present in the scene.

What is computer vision then? Its goal is also to analyse a scene, but a more global view of the problem is taken. Marr's now classical *computational theory of vision* [Mar82] is accepted as a form of definition. He advocates a clear separation between a rigorous analysis of the tasks to be performed, how to represent and process information, how to implement the processes. In order to reinforce the shifting ground on which they are working, computer vision researchers often look at what is happening in neurophysiology and psychology.

More concretely (and very roughly) speaking, computer vision involves [Bal82] [Bra82] [Bes85] [Rea87] [Shi87] [CVGIP] [CVPR]:

- extracting image primitives for describing the scene (*low-level vision*);
- describing models of objects potentially present (*model base*);
- from an initial scene description, hypotheses regarding the scene content are made. They are validated or rejected using knowledge stored in the models base (*high-level vision*);
- the process iterates until all objects are recognized.

Needless to say, computer vision systems perform correctly only in rather simple, well controlled situations.

1.1.3 Evolution.

Progress in image analysis is slow, and many paths are being explored in order to proceed. As one of these options, links with image synthesis are being investigated.

On the other hand, image synthesis seems to progress very rapidly. A closer look reveals not only that the pace is slowing down but that rapid growth has often been chaotic. Issues of interest become more complex, and cannot simply be solved by some clever *ad hoc* technique. Conceptual research is gaining importance; it often happens that image analysis offers interesting and relevant hints.

Overlaps between the two fields are becoming numerous. As an example, a computer vision system needs to take into account illumination models, projections and transformations, and use knowledge from a graphics object modeller. Synthetic image generation might use techniques and theories once typical of image processing, such as anti-aliasing, sampling, filtering, stochastic modelling. There are applications where "real" images coming from an external source are rendered using scientific visualization techniques, then mixed and treated together with synthesized scenes. The purpose of this report is to try to present a good overview of these overlapping areas.

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* Apart from this subsection (§1.1.2), *image analysis* is used without distinction for image processing, image analysis and computer vision.

1.2 Overlaps.

There are a number of ways in which common ground between image analysis and synthesis can be looked for. Three broad headings to consider could be a *common theoretical basis* (or *concepts*), *common areas of study*, and *common applications*. The distinctions between these three categories is somewhat arbitrary: the classification could certainly have been different.

Common theoretical concepts constitute the most profound aspect of the overlap. The first and most obvious interest in listing common underlying theories is to suggest different and/or new ways of approaching a given problem. More generally, such a list can help in establishing that the two subject areas, analysis and synthesis, have the same core and constitute a single field.

Common areas of study can either be very broad, like object-oriented programming, parallel hardware or shape representation, or else more specific branches of knowledge, like the interaction of light with surfaces or multi-dimensional Fourier analysis. Identifying such common areas of study would be useful in order to prevent duplication of effort.

The distinction between “Common Theoretical Concepts” and “Common Areas of Study” is understood as follows. Common theoretical concepts are taken to be core theories of a rather fundamental nature, which could constitute the basic corpus on which a common discipline might be built. Common research areas have a broader support and possibly a narrower scope. They are often built on the common theories. As an example, modelling (§3) uses elements from geometry (§2.6), linear and stochastic paradigms (§2.4 and §2.5), mathematics (§2.8), and perception (§2.2). Common areas of study could still exist even if the fields were not merged, although having many such common areas would imply a deeper connection between the subjects.

Common applications that make use of both image analysis and synthesis techniques certainly constitute the most visible part of the overlap. Common applications arise when an application has to bridge the two areas; this can happen in rather diverse fields. Besides typical applications like interactive image processing, many other avenues towards cooperation are being investigated.

1.3 Common basis for image synthesis and image analysis.

Computer science has difficulties in proving to itself, as well as to the outside, that it constitutes one coherent domain. A very similar problem occurs with image analysis and synthesis: they seem to be picking up notions from various fields, such as information theory, mathematics, signal processing, neurophysiology, psychology, etc. There is one common factor though: *images*. A French neologism employed to qualify both analysis and synthesis, *imagerie*, seems very appropriate in this respect. *Imagery* in English could play a similar role.

We argue that computer graphics is intimately concerned with perception. The physics of display certainly has influence over what is observed, but what really matters is the internal representation to which a given image refers and which it seeks to recreate in the user. If the stages of the graphic generation pipeline can be conceptually extended to take into account such internal representations, algorithms could be designed to convey the intent of the graphic designer more fully.

The problem of representation is also the key to a computer vision system. If the internal representation that humans have of objects were known, the tasks needed for recognition might be much more easily reconstructed. There is no consensus however on this very fundamental matter. Typical is the opposition between holistic visual analysis, as exemplified by the neural network paradigm, and a step-by-step deductive analysis, characteristics of knowledge-based vision systems.

It seems therefore that the common basis for synthesis and analysis lies in the way we see things. This statement is not new. It could also be an illusion: knowing how we perceive objects might be of no help in image synthesis or analysis. Aeroplanes do not flap their wings like birds. Perception seems however to be the only door through which really new concepts might arrive.

More concretely speaking, there is a rapidly growing awareness of the need for links between the methods of image analysis and image synthesis. Literature already exists on this theme of “common topics” [Ekl85] [Pav88] and descriptions of common algorithms have appeared [Pav82]. Projects are being conducted where cooperation between analysis and synthesis is explicitly put to work. For example, a general approach for scene analysis is proposed in [Gag89], where the differences between a reconstructed synthetic scene and the original image should help in improving the scene model being constructed. Workshops and seminars are being held [Com89]. Other references unifying analysis and synthesis are given below.

2. Common theoretical basis and concepts.

What follows is a list of theoretical concepts that present some interest for both image synthesis and analysis. Concepts are followed by examples of their use; the order in which they appear is arbitrary. Explanations have been purposely kept to a minimum: this is not intended to be an exhaustive description of all possible fields. Common concepts have certainly been missed.

Theoretical studies seem to have been rather more neglected in image synthesis than in image analysis, and this lack of attention has been bemoaned before [Ear87]. An exception is the controversy which arose regarding “physical realism” [Gre88] *versus* “faking” [Ree87] [Ree88]. Greenberg argued that the prime basis for advances in image synthesis is physics, while Reeves defended faking. The problem with faking is of course its *ad hoc* nature—we want to provide a theory which encompasses faking: an understanding of the perception of raster displays must be an essential component of such a theory.

The more subtle version of the above controversy is whether a clean break has to be made between the physical and perceptual stages of the image synthesis process [Mey86], or whether the ultimate act of perception should inform all stages of image synthesis. This issue is left as an open question for the time being.

It is curious that while human factors play an acknowledged role in interactive computer graphics (how could things be otherwise?), they do not play a greater role in the more theoretical aspects of image synthesis. As an example, very little attention is paid to the possible manners humans model objects. In image analysis though, such problems of knowledge representation, as well as other aspects of perception, are often felt to be essential. This could be one major contribution of image analysis to image synthesis.

2.1 Common assumptions.

Linked to the way we see things are various assumptions that are made when looking at a scene. They are sometimes explicitly exploited in particular algorithms (such as coherence, in synthesis algorithms, or in modelling [Ekl85]), but most often implicitly. The most generally accepted assumptions are:

- a two-dimensional projection of a three-dimensional scene is sufficient for its interpretation;
- a formal description of a scene exists;
- a simple description of a scene is more plausible than a complex one;
- objects of interest are rigid, or can be decomposed into rigid objects;
- objects of interest have a degree of coherence and continuity, and usually are of a non-stochastic nature;
- random structures are non essential. In image analysis, they are considered of lower interest. In synthesis, their principal function is to increase realism.

Most of these assumptions are summarized by the *hypothesis of well-behaved world*.

2.2 Perception.

As mentioned in section 1.3, perception is certainly the most unknown and possibly underexploited area. Generally speaking, the physiology of the primary visual pathways has been fairly well explored; retina, optical nerve, organization in the cortical areas, etc. [Hub77] [Barl81] [Liv84] [Tho90]. What happens “inside” however is almost entirely unknown. A modular organization of specialized areas postulated, with multiple links between these areas [DeY88]. Maybe the single statement which summarizes best the complexity of the human visual system is that the analysis of any scene is performed in less than a second in fewer than 100 processing steps [Ros87] [Tho88].

Anatomy and physiology provide a good knowledge of the primary visual pathways. For higher functions however, insights can only be obtained through psychophysical experiments. Which usage to make of such data is a key issue. These studies have so far reinforced the conviction about the following postulates for image analysis:

- *realizability*: humans see, it should therefore be feasible to have a machine doing so;
- *anthropomorphism*: useful knowledge comes from the human visual system. As a starting point, this system can be tentatively imitated;
- *reductionism*: computer vision systems are decomposed into modules. This point of view is in opposition to the more holistic approach of the neural networks and connectionism community.

Important concepts in perception:

- systemic approach of the human visual system [Cor70] [Liv87] [Chu88]:
    - for analysis and synthesis: modules;
- physiology of specialized receptors:

  - analysis: contour detection [Hub77] [Por88], chromatic and geometrical invariants [Des85], stereoscopy [Mar82], frequency and orientation analysis [Por88], spatial and temporal interpolations;
  - synthesis: colour (see §2.3 below);
- connectionism paradigm [Rum86]:
  - analysis: primitive extraction, shape representation and recognition;
- psychophysics, human visual perception [Cor70] [Cav87] [Tho88] [Tho90]:
  - analysis: better understanding of human visual system modules;
  - synthesis: underlying assumptions for rendering, animation [Bla89] [Wat86] [Fer88];
- cognition [Gib82] [Pyl84] [Min86] [Gri87]:
  - analysis and synthesis: knowledge acquisition and representation;
  - synthesis: realism [Ger89], reasoning in intelligent CAD [Tom85] [Tak87].

2.3 Light.

Two different matters are exposed here. The first one concerns the way a scene is illuminated, with problems of reflection, shading, etc. [Coo81] [Ger89]. The second aspect is related to the way human observers perceive what appears on displays [Ros48] [Cor70].

The usage of illumination and reflectance models in synthesis is almost as old as the field, whereas it is more recent in image analysis; this is a good example of knowledge transfer from synthesis to analysis.

Concepts:

- illumination and reflection models [Pho75] [Coo81];
  - analysis: shape inference from shading [Hor77], from specularities [Buc87], etc.
  - synthesis: local surface behaviour;
- global illumination methods [Rog85]; ray tracing [Whi80] [Rot82], radiosity [Gor84] [Gre86]:
  - analysis: synthesizing images to verify analysis [Gag89];
  - synthesis: realism [Ger89];
- colour [Fol82] [Ger87] [Sch87] [Mur89]:
  - analysis: segmentation [Ohl78] [Oht80], indices for recognition [Lan83] [Sha84] [Kli88], material identification [Nag79] [Rub88];
  - synthesis: realism;
- determination of an appropriate colour space:
  - analysis: coding [Rea73], segmentation [Fau79] [Oht80];
  - synthesis: presentation [Sch87] [Mur89];

- histogram manipulations:
  - analysis: gamma-correction, enhancement [Pra78];
  - synthesis: lookup table modifications [Fol82].

2.4 Linear or quasi-linear paradigm.

Images are signals, and as such can be operated upon [Sha48] [Ahm75] [Opp75] [Ros82] [Wah87] [Sig88]. An operator processes an input signal, and produces an output. The basic operation is the convolution product; Fourier transformation is used either as a representational formalism, or simply as a means of calculation. For various practical reasons operators are often not exactly linear; still, their mode of operation is convolution like. The following concepts are good examples of knowledge transfer from analysis to synthesis.

Concepts:

- information theory [Sha48]:
  - analysis and synthesis: acquisition, storage transmission;
- sampling theory [Opp75] [Ros82] [All84]:
  - analysis: data acquisition, coding, image compression;
  - synthesis: ray tracing, anti-aliasing;
- interpolation [Pav82] [Ros82] [Pav88]:
  - analysis: resampling, interpolation, coding;
  - synthesis: curve or surface fitting, in-betweening;
- orthogonal transforms [Rea73] [Ahm75] [Ros82]:
  - analysis: filtering, coding, parameter extraction, optimal colour space selection;
  - synthesis: anti-aliasing, texture generation;
- filtering [Ros82] [Gon87]:
  - analysis: preprocessing, segmentation;
  - synthesis: smoothing, post-processing.

2.5 Stochastic paradigm.

All signals are stochastic. If this is not taken into account vision systems fail to recognize objects and synthetic images look ... artificial. Stochastic process modelling not only allows more realistic synthesis, but also provides a better characterization of which parameters to extract for an analysis. Besides the object modelling problem, there is also often interest in giving a “stochastic touch” to normally deterministic methods.

Concepts:

- stochastic modelling of textural processes:
  - analysis: parameter extraction for segmentation, coding [Har79] [VGo83] [Uns89], Markov fields models [Gem84];

  - synthesis: texture generation [Gag87];
- stochastic modelling of fractal processes [Man77]:
  - analysis: image compression [Bar85];
  - synthesis: simulation of natural surfaces [Sci88];
- other stochastic models of natural phenomena, e.g., faces, trees, waves, etc. [Eurographics] [Siggraph] [Lew87] [Ree83]:
  - analysis: parameter characterization;
  - synthesis: simulation;
- stochastic sampling:
  - analysis: random sampling (mostly for 1D signals);
  - synthesis: stochastic ray tracing (for anti-aliasing etc.) [Coo86];
- simulated annealing [Gem84]:
  - analysis: restoration, edge extraction, texture segmentation [Aze87];
  - synthesis: optimization of colour quantization [Fiu89b].

2.6 Geometry.

Geometry is understood here as matters which concern various levels of image formation; geometry in the mathematical sense is detailed in §2.8. When synthesizing a scene, three-dimensional objects defined in their master coordinates are subject to various transformations and finally projected onto a two-dimensional plane. Image analysis deals with the same transformations, but in an inverse manner: they need to be recovered from the 2D image. Other geometrical problems are those linked with surface or image deformations. Finally, data structures may reflect different geometries for processing images.

Concepts:

- geometrical transformations for displacement, i.e., translation, rotation, scaling, symmetry [Fol82] [New81]:
  - analysis: recovering objects’ position;
  - synthesis: scene composition;
- geometric invariants and regularities:
  - analysis: viewpoint independent object recognition [Par86] [Wei88], regularities and symmetry detection [VGo89a];
  - synthesis: curve and surface shape description in CAD and graphics [Bez89] [VGo89b];
- projective transformations for imaging [Fol82] [New81]:
  - analysis: recovering camera parameters (calibration problem) [Lon81];
  - synthesis: display transforms;

- stereo vision:
  - analysis: calibration problem [Str84] [Fau86], stereopsis [Mar76], reconstruction [Shi87];
  - synthesis: depth rendering, binocular displays;
- surface deformations:
  - analysis: geometric corrections [Hal79] [Uns87];
  - synthesis: mapping of patterns, e.g., texture [Gag87];
- raster geometry:
  - analysis: sampling [Ros82], tessellating [Sri81], hexagonal [Ser82];
  - synthesis: bit-mapped graphics [Fiu87] [Fiu89a];
- other representations [Sri81], such as multi-scale (or pyramidal):
  - analysis: feature extraction [Bur83];
  - synthesis: filtering, texture mapping [Wil83] [Hec86] [Gla86] [Cro84] [Fou88].

2.7 Physics.

Notions drawn from classical physics appear more and more on the scene: a deeper understanding of natural phenomena is mandatory in order to progress.

Concepts:

- light & colour: see §2.3;
- material physics:
  - analysis: intrinsic characterization of objects;
  - synthesis: surface properties for realism;
- dynamics, kinematics:
  - analysis and synthesis: modelling of movement;
- forces, electromagnetism:
  - analysis: active curve fitting [Kas88], grouping of image primitives [Pun89];
  - synthesis: generalized splines [Pin88], affinity browser [Pin89].

2.8 Mathematics.

Well established theoretical concepts from mathematics are (knowingly or unknowingly) used in every imaging application.

Concepts:

- logic, set theory, algebra:
  - analysis: syntactic pattern recognition [Fu74];
  - synthesis: constructive solid geometry [Req82], symbolic geometry [Bow87];

- calculus, matrix algebra:
  - analysis and synthesis: coordinates (e.g., quaternions [Sho85] [Ple89]), geometrical transforms;
  - analysis: image restoration [Hal79], orthogonal transforms [Ahm75];
  - synthesis: radiosity [Hal89] [Gor84];
- approximation theory:
  - analysis: curves and surfaces approximation for modelling [Pen86], coding [Ede85] [Ede86] [Uns90] and recognition [Per78] [Bal82] [Uns87];
  - synthesis: surface and curve approximation methods, splines [Faux79] [Pav82] [Lan86] [Pav88];
- geometry, topology:
  - analysis and synthesis: basic geometry [Bow83], geometrical reasoning (robotics, animation), connectivity and area filling [Pav82], mathematical morphology [Ser82];
  - analysis: distances, connected component labelling [Ros82];
  - synthesis: algebraic geometry for intersection computation;
- computational geometry [Faux79] [Lee84] [Meh84] [Sha75]:
  - analysis: scene description;
  - synthesis: spatial occupancy, intersection, modelling, algorithmic analysis;
- discrete mathematics:
  - analysis and synthesis: complexity (see also computational geometry);
  - analysis: matching.

2.9 Computer Science.

Although mathematically oriented, some concepts are characteristic of theoretical computer science. They are often included in the so-called artificial intelligence methods.

- basic computer science: logic, automata, languages, algorithms, data structures;
- applied computer science: see §3, “Common areas of study”;
- geometric reasoning [Arb88]:
  - analysis: scene description;
  - synthesis: animation, intelligent CAD [Tom85];
- knowledge representation [Win84]:
  - analysis: description, knowledge-based systems [Bal82] [Bro84];
  - synthesis: symbolic graphics [Arb87];
- classification / clustering:

- analysis: statistical [Dud73] or syntactical [Fu74] pattern recognition;
- synthesis: parameter selection, fast classification of rays, point membership.

3. Common areas of study.

The common concepts described above may be taken as core theories which could constitute a basic corpus for an imagery discipline. Common research areas described in this section are often built using those common theories. Instead of detailing each area again, it is simply indicated when appropriate what the relations to the previous concepts are. Notice that the same subject can be a core theory or a common study area, because on the one hand it can be regarded in a theoretical sense as a constituent of an overall theory, and on the other hand it can simply be mined in isolation to extract its applications for image synthesis and analysis.

- computing hardware [Stu89] (*computer science, mathematics*);
  - concurrency, parallelism, distributed systems;
  - networking;
  - storage technology (*linear paradigm*);
- peripheral devices: monitors, printers, cameras, etc. (*perception, linear paradigm*);
- computer software (*mathematics, computer science*):
  - data structures [Ekl85];
  - languages, e.g. object-oriented languages, e.g. Smalltalk [Gol83], functional languages [Ary86] [Burt89] [Sal87];
  - standards [Hop83] [Bon85] [Hat82] [Wiß86] [How89] [Hub89];
- user interface, human factors [Lip88] [Shn83] [Pav88] [Mye89] (*perception*);
- modelling shape [Req82] [Ekl85] [Bes88] [Far88] (*perception, geometry, linear and stochastic paradigms, physics and mathematics, etc.!*). The following general approaches have been attempted:
  - polyhedral object modelling [Req82];
  - curved objects modelling, for example with splines [Fol82], hyperquadrics [Barr81] [Pen86], spherical harmonics [Bal82];
  - sweep representations, such as generalized cylinders or cones [Bal82];
  - modelling in a parameter space, such as with the Gaussian sphere [Bra82] [Bes85], or in the so-called arc-length space [VGo89a] [VGo89b];
  - modelling aspects of objects, for example using critical points [Koe82] [Ric85];
- modelling of surface structure [Ekl85] (see §2.5, *stochastic paradigm*);
- optic flow analysis of change in images over time [Gib79] has long been used in computer vision e.g. [Koe75] [Lee80]. There have also been some attempts to apply it to image synthesis [Gri87] [Bla89];

- interactive image synthesis and image analysis also have common areas of study at more abstract levels than images and models. Higher level understanding and reasoning has obvious applications in image analysis and perhaps less obvious applications in CAD [Tom85] [Bij87]. Graphical search and replace [Kur88] and beautification [Pav85] requires some recognition of objects in a drawing in order to adjust their shape or other properties.

As this rather limited list indicates, it is much harder to identify common areas of study than common theoretical concepts. This may partly come from the somewhat arbitrary nature of the separation between §2 and §3. More fundamentally however, this shows how distant from each other image analysis and image synthesis are. As the next section "Common Applications" indicates, they often coexist, but rarely cooperate.

4. Common applications.

Common applications, that make use of both image analysis and synthesis techniques, certainly constitute the most visible part of the overlap. The list could be longer and more detailed than here; only prominent and general applications are presented to illustrate the point.

Image reconstruction [Pav82] [Ros82] and visualization [Eurographics] [Siggraph] encompasses several domains of application where analysis and synthesis have met long ago. One of their characteristics is the need to acquire, process, and present users with large amounts of data. The most well known of these domains is certainly *medical imaging* [CMIG] [IEEE-MI] [Skl86] [Pro88] [Tow90], where abundant use is made of pseudo-colouring, three-dimensional reconstruction from two-dimensional structures, realistic display of volumes, etc.

Computer vision systems [Bal82] need to take into account illumination models, projections and transformations, and use knowledge from a graphics object modeller. Even simple *robotic* or *industrial vision* systems have to integrate such concepts. A general approach for scene analysis is being investigated by a French INRIA team [Gag89], where parameters extracted from the scene drive an image synthesizer. The difference between the synthetic and natural images should help in improving the scene model being reconstructed.

Computer-aided design, once the realm of image synthesis, has more and more in common with image analysis. Intelligent CAD is reminiscent of computer vision systems [Tom85]. Recent developments in CAD objects modelling have strong links with free-form modelling for vision [Bez89]. Perception becomes an issue: humans easily and extensively use shape regularities such as symmetry or periodicity when confronted with the task of object description and recognition. CAD designers also generate their object models on the basis of elementary shapes which are combined with a set of transformations, an important class of which are object symmetries. Emulating such structural object descriptions not only strongly appeals to human intuition [VGo89a] [VGo89b], it also opens perspectives to vision-CAD coupling. Bringing vision into the realm of CAD is of enormous economic importance.

Synthetic image generation can make more use of many techniques and theories once typical of image processing. Anti-aliasing can be performed using filtering [Pav88]; sampling has applications in ray-tracing [Coo86]; stochastic process theory is relevant to modelling, etc.

Image coding, traditionally on the image analysis side [Kun87], is reaching some limits in terms of compression ratio. In order to reduce the quantity of information to be stored and/

or transmitted, current approaches try to make use of computer graphics concepts. A first approach is as follows: some components of the image are first identified; a few relevant parameters are extracted and then stored and/or transmitted. When needed, these parameters allow a more or less faithful synthetic reconstruction of the original scene. Results have been obtained with human heads or bodies [Hua89]. Another approach for reaching better image compression ratios is by encoding the stochastic parts of images using fractals [Bar88].

Television (TV) and high-definition television (HDTV) associate analysis and synthesis. Classical television has given a formidable impetus to the imaging hardware industry. TV shots more and more incorporate synthesized sequences. Newer digital TV sets contain elements once typical of high-end graphic workstations, such as frame buffers. Various image analysis concepts are used in the following areas [Ton89]: receiver processing for improved display, bandwidth compression for TV and HDTV transmission [ImComm89], motion compensation, optimal selection of colour spaces. Finally, TV and HDTV emphasize the need for general purpose image standards [Sab89].

Model database creation can make use of both analysis and synthesis. In addition to traditional morphological data acquisition techniques, image analysis can be used as an input tool for image synthesis, for example to enter three-dimensional models (and so reduce the number of teapots in graphics illustrations). Image analysis can also be employed to convert paper drawings to computer representations; more radically, the camera could become the principal input tool for interactive image synthesis [Jar77].

Interactive image analysis is of course the most obvious area in which image synthesis cooperates with image analysis. The theoretical basis for this lies in the fact that the only fully functional visual system to which we have access is our own. Many image analysis tasks become practical only when it can be guided by a user and if difficult cases can be referred to a human arbiter. (This argument applies to many AI applications, but because of the visual nature of most computer interaction tools it has particular force with image analysis). A good example of the creative use of interactive image synthesis for image analysis is [Kas88].

5. Conclusion.

The aim of the present report was to demonstrate how deeply related image synthesis and image analysis are. A list of theoretical concepts has been given which could constitute the basic corpus on which a common discipline might be built: *imagery*. Common areas of interest as well as applications have been presented, exemplifying the advantages of relating analysis and synthesis.

An examination of some of the concepts listed above might reveal interesting areas of research, where a given notion has so far been used exclusively in analysis, or synthesis. As examples, the following image analysis concepts could be of help for image synthesis: filtering, for postprocessing; multi-resolution, for example for ray-tracing; local activity and energy measures, for example to determine where to trace rays; decomposition of colour space, for example to perform anti-aliasing in the luminance channel only; the connectionist approach; etc.

Conversely, image analysis could benefit from concepts traditionally associated with computer graphics: radiosity for extracting shape information; deep modelling of physical phenomena; standardization of image formats as well as algorithms; etc. Finally, there are many unexplored areas from which both image analysis and synthesis could benefit; this is typically the case with perception.

The distinction between image synthesis and image analysis has outlived its usefulness. The absolute differences can be discarded; what remains is a great commonality of interest.

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