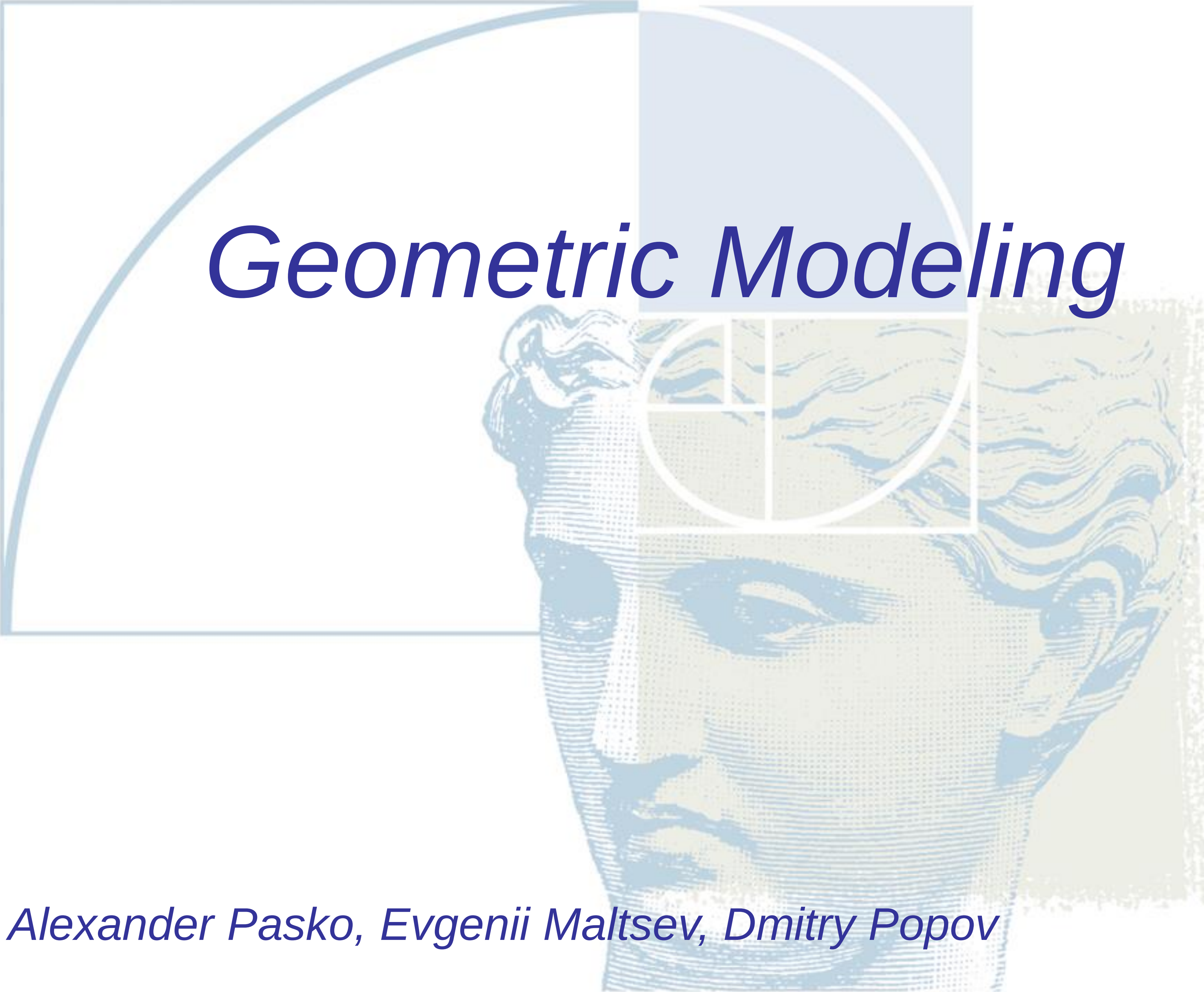
Geometric Modeling



Alexander Pasko, Evgenii Maltsev, Dmitry Popov

Unit materials

- Lecture notes
- Seminar handouts

are available at

http://gm.softalliance.net/

Advice: download and print lecture notes before the next lecture

Geometric Modeling Applications

Contents

- What is geometric modelling?
- Why shape modelling?
- Research and application areas
- Shape modelling application system
- Digital media system
- Reference materials

What is Shape Modelling?

Shape Modelling is a human activity on introduction, creation and analysis of an object (model), which reflects some shape properties of another object (the original).

What is Shape Modelling?

Examples:

- Drawings

Matobos National Park, Zimbabwe

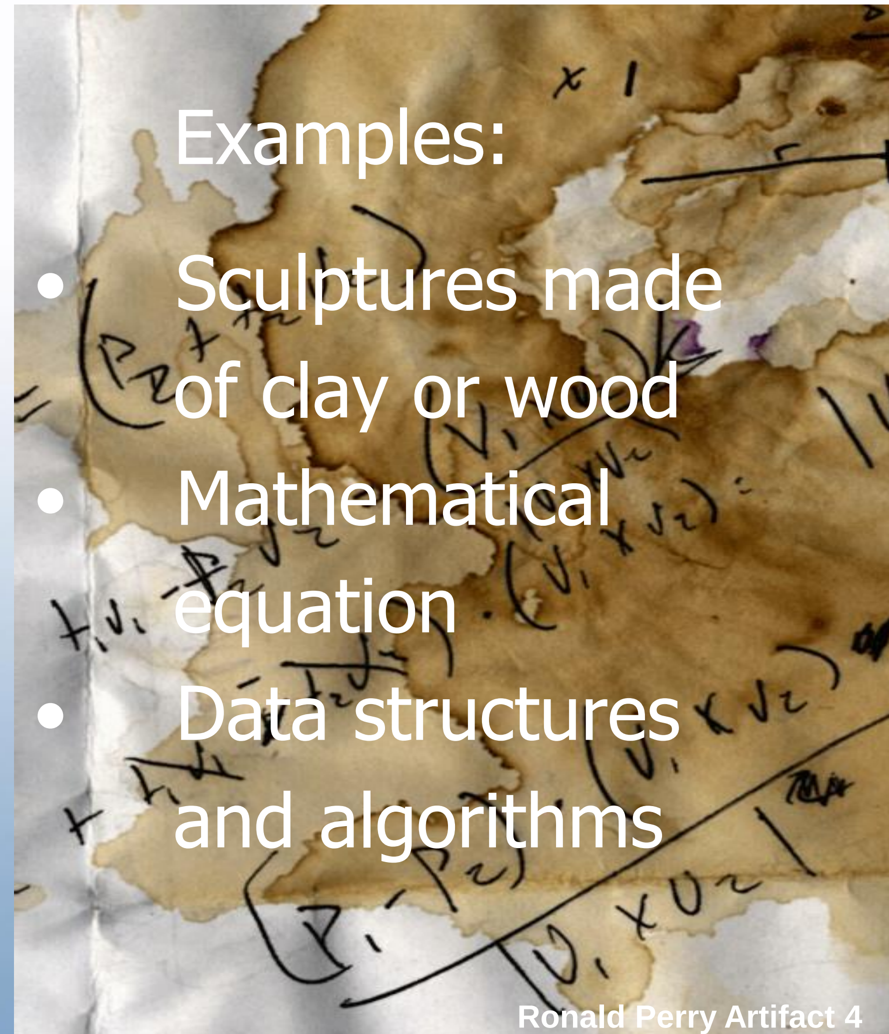
The cave of Lascaux

What is Shape Modelling?

Detail from **The Invention of Drawing**, 1830: Karl Friedrich Schinkle

What is Shape Modelling?

Auguste Rodin
“The secret”



Examples:

- Sculptures made of clay or wood
- Mathematical equation
- Data structures and algorithms

Ronald Perry Artifact 4

What is Shape Modelling?

Computer-based Shape Modelling is an area of computer science which studies mathematical and numerical methods and tools for creation, manipulation, analysis, and storage of shape models.

Why Shape Modelling?

Geometric Modelling is traditionally connected to parametric curves and surfaces.

Many other different models for point sets have emerged:

- implicit surfaces,
- constructive solid and volume models
- topological models
- grammar-based models (L-systems, fractals)
- and others.

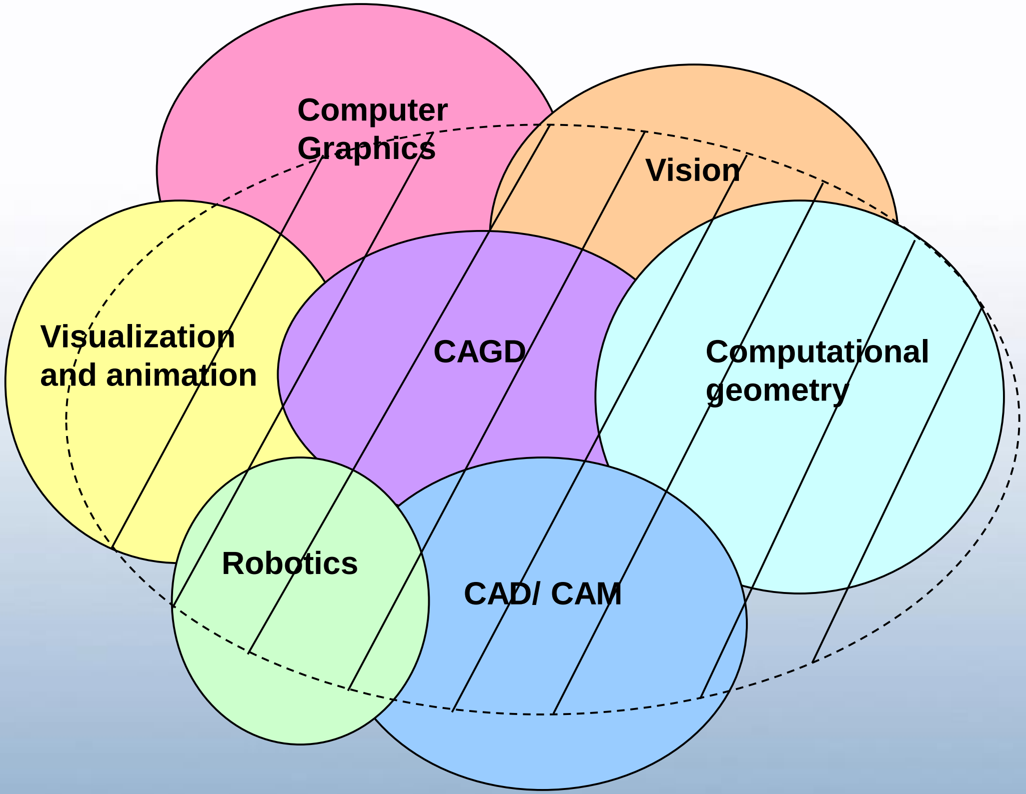
Why Shape Modelling?

The term “Shape Modelling" has been introduced to provide a roof for all new models of point sets.

Shape Modelling can be defined as an area of computer science studying methods and tools for modelling point sets in geometric spaces

(N-dimensional Euclidean space).

Research and application areas



Relationships of Shape Modelling (shaded region) with other research and application areas:

- Computer Graphics
- Visualization and animation
- Vision
- Computer-Aided Geometric Design CAGD
- Computer-Aided Design and Manufacturing CAD/ CAM
- Computational Geometry
- Robotics

- Computer graphics

  Computer graphics can be roughly partitioned into shape modelling, rendering, and graphical input/output.

- Computer vision and image processing

  Between image pixels and perception, there is the reconstruction of shape from one or more views of a scene.

- Computational geometry

  is concerned with geometric algorithms on sets of objects and with theoretical efficiency of the algorithms.

- Visualization and animation

  Visualization covers techniques of visual representation of numerical and other types of data in the form of images and animations; especially for large amounts of data typically obtained from sensors such as satellites and body-scanners an intermediate shape model is needed.

  Artistic computer animation and games (real-time interactive animation) are mainly based on shape models.

- Computer-aided geometric design (CAGD)

  studies parametric free-form curves and surfaces.

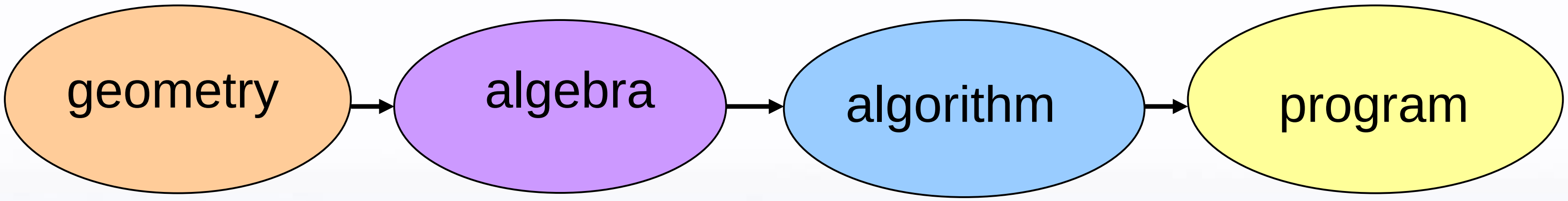
- Computer-aided design and manufacturing (CAD/CAM)

  CAD includes mechanical, architectural and other shape design and solid Modelling systems. For manufacturing, a shape model is converted to commands of numerically controlled (NC) machines taking tools geometry into account.

- Robotics

  The problems of dynamics and path planning influence shape models and related geometric calculations (moments of inertia, trajectories, and offsets from surfaces).

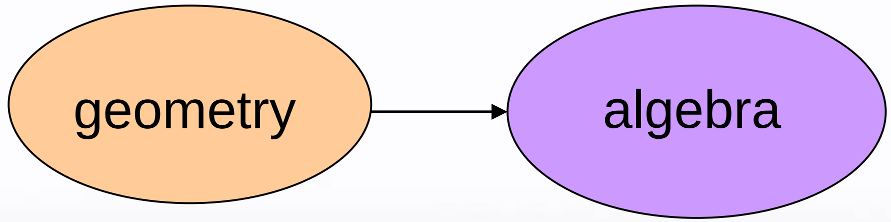
From geometry to program



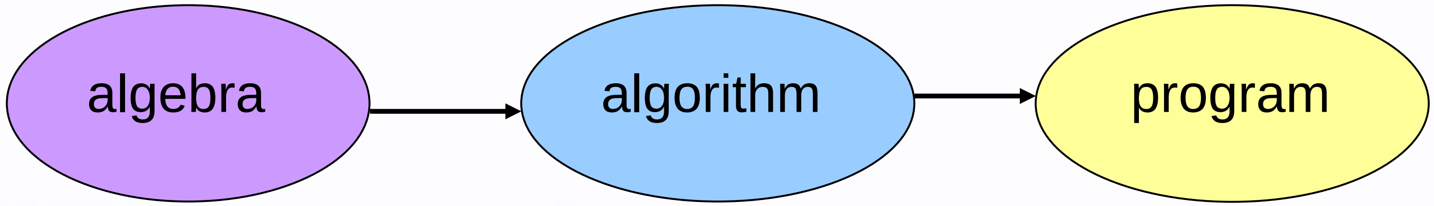
In a shape modelling system, a shape model, shape transformations and analysis are implemented in the form of software programs.

To get from a geometric concept to a program, we need to go through the shown sequence.

From geometry to program



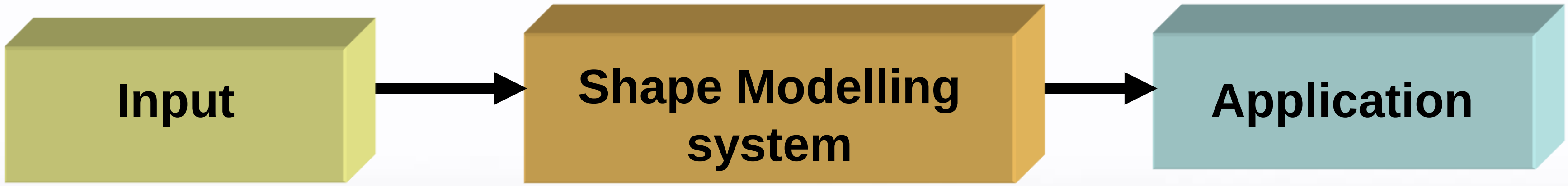
- Informal description of a geometric problem
- Conversion of a problem description to an algebraic form in a coordinate system
- Decision on what has to be solved to find the solution (equation, system of equations)
- Formulation of requirements to algorithmic solution



Levels of algebra to algorithm transition:

- Symbolic: the algebraic system level
- Analytic: the algorithm is the direct implementation of an algebraic solution
- Numerical: there is no closed form analytic solution, but a numerical method can be used
- Approximate: there is no algebraic solution and we are working with simplifications

Shape Modelling Application System



- User actions
- Programming language
- High-level geometric language
- Geometric data

- Shape representation
- Shape transformations
- Model conversion
- Shape analysis
- Export of models

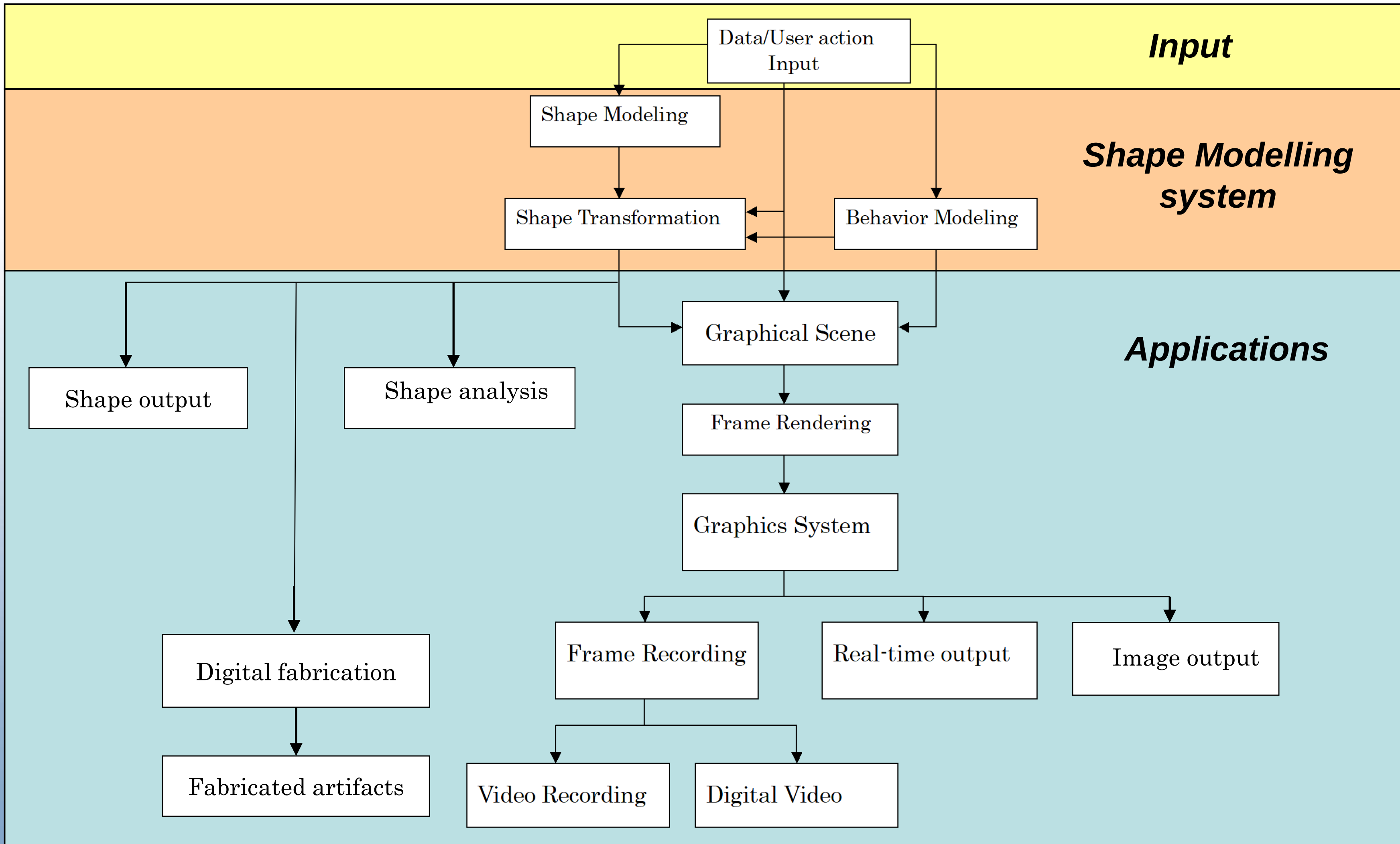
- Visualization
- Digital media
- Analysis of geometry and topology
- Calculation of physical properties
- Rapid prototyping
- Manufacturing
- Data base storage and exchange

Shapes in Digital Media

Shapes are likely to become the next wave of digital multimedia content, after

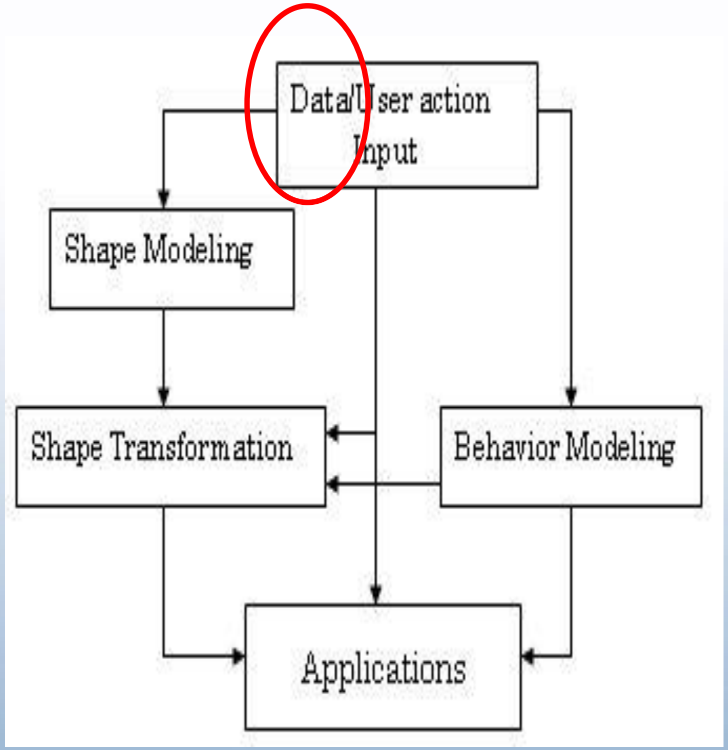
- sound in the ’70s
- images in the ’80s
- video in the ’90s
- technology is converging to support the creation and delivery of high fidelity, high performance shape content (3D, 3D+T)

General Digital Media System Structure



Input Data

- “Data” means digitally represented information
- Source of data: observation, measurements, simulation
- Data types:
  - continuous function
  - scalar, vector, tensor
  - connectivity and hierarchy



Characteristics of Input Data

- Nominal, ordinal, quantitative
- Continuous data
- Discrete data
- Topology/ structure data

- Nominal data
  - members of some class:
  [Tokyo, Moscow, Tirana] or [orange, apple, grapefruit]
- Ordinal data
  - show an order:
  [low, medium, high] or [tiny, small, large, huge]
- Quantitative data
  - precise numerical values: 1, 2.5; 0.3E-11

Continuous Input Data

Functions: $\lambda_i = f_i\,(X)$, where

$X = (x_1, x_{2,\ldots,}\, x_n)$, i=1, ..., m

x_j are independent variables

λ_i are dependent variables ("parameters", attributes)

n>3 multidimensional, multivariate data

m>1 multiparameter data

Discrete Input Data

- Scalar (single integer or real numerical value)
- Scalar array
  - indexed set of scalar values
  - 1D (linear) array: samples of $y = f(x)$
  - 2D array: image or samples of $z = f(x,y)$
  - 3D array: volume data (3D image) or samples of $\lambda = f(x,y,z)$
  - 4D array: time-dependent volume data or samples of $\lambda = f(x,y,z,t)$
  - nD array: hypervolume data

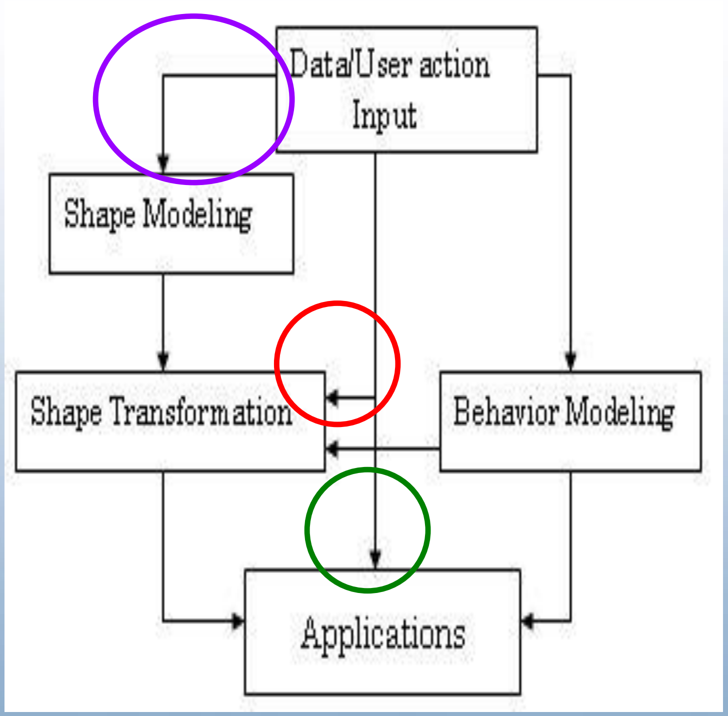
Topology/structure data

Discrete data structure:

- Sequential (text)
- Network (hypertext, molecules, Web)
- Hierarchical (catalogs)
- Relational (databases)

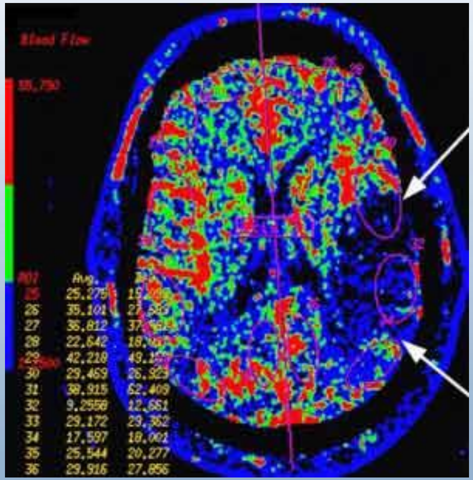
Input Data

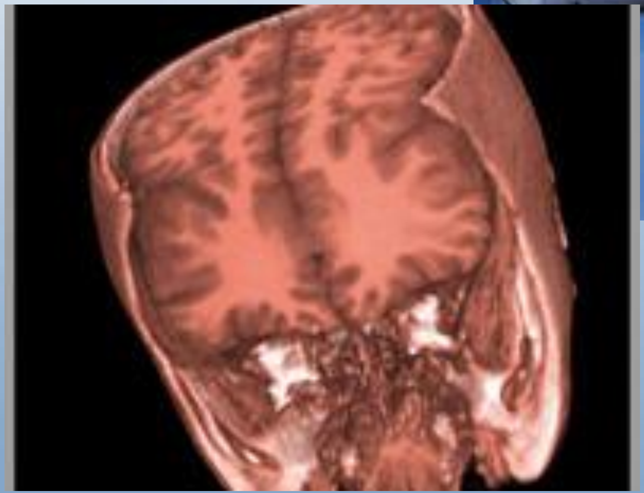
- for Modelling
  - scanned 3D surfaces and volumes
  - terrain data
  - CAD models
- for Animation
  - motion data: off-line simulation and motion capture
- for Rendering
  - images
  - 2D and 3D textures
  - surface properties



Input data: Volume scanners

Volume scanners (CT, MRI) provide density information slice by slice in 3D voxel arrays.





Volume Rendering

Input data: Motion capture of hand

- Special gloves with sensors transform hand motions into real-time digital data on position and orientation of
  - wrist
  - palm
  - fingers
- Use: interaction with real-time animation, control of character motion

CyberGlove

Images by Immersion Corporation

Input data: Motion capture of full body

- Motion capture employs special sensors, called *trackers*, to record the motion of a human performer.

- Then the recorded data are used to generate the motion for an animation.

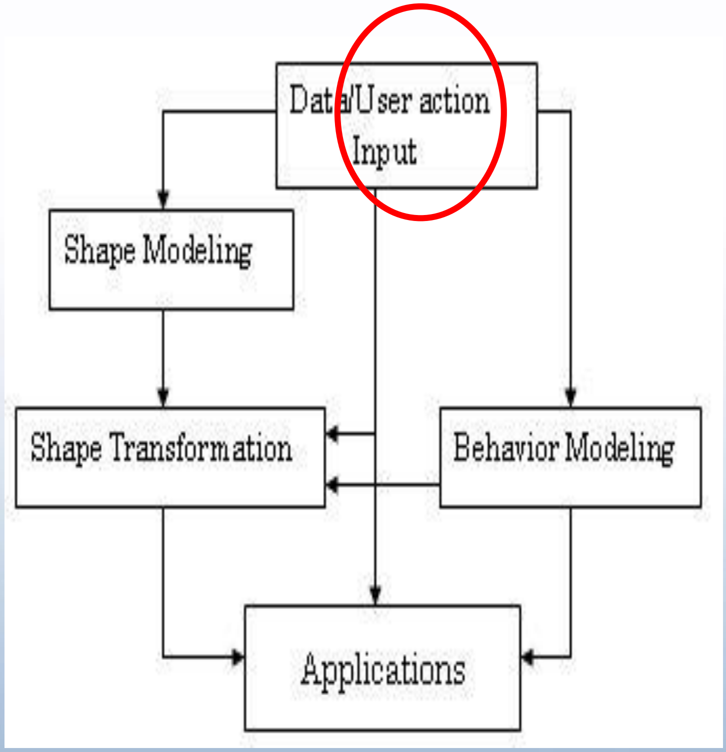
Full body magnetic tracking system

Image by B. Bodenheimer

User Actions

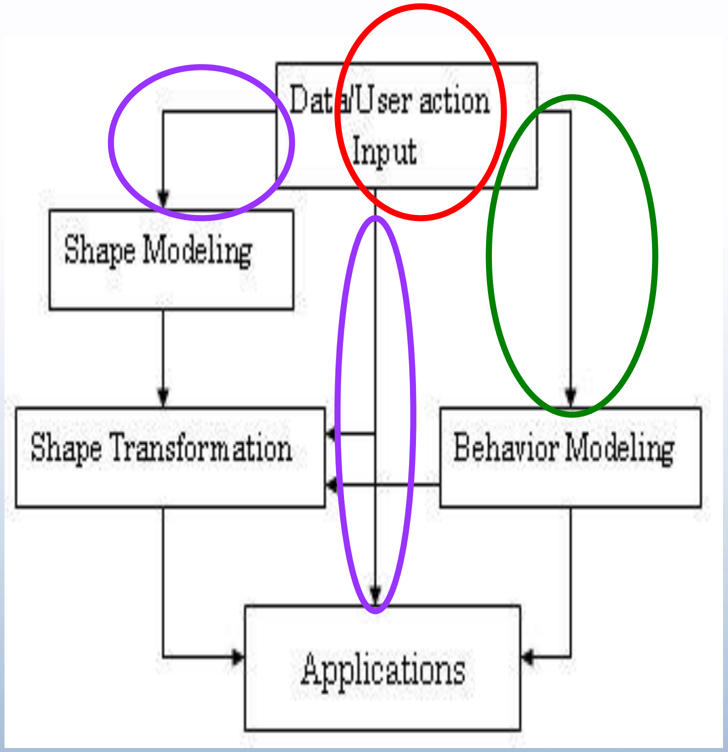
Basic interaction level:

- Choice: selection of one of possible alternatives (menu)
- Location: coordinates of a point or group of points (glove)
- Selection: ID of a selected shape or an image
- Value input: integer or real parameter value (rotation angle)



User control actions (games, virtual reality and driving or flight simulators):

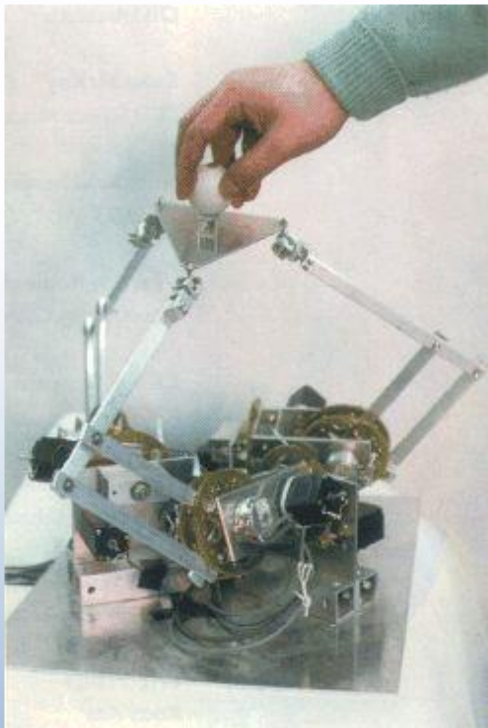
- Basic level +
- Hand and fingers data
- Head position and orientation
- Other body, haptic, voice, etc., data



Haptic Interface

- Haptic devices are related to the sense of touch. The Greek word *haptikos* means to grasp, touch.
- *Force feedback devices* simulate resistance of material to pressure
- *Tactile display devices* stimulate the skin to generate sensations of contact: high-frequency vibrations, small-scale shape or pressure distribution, and thermal properties.

Force feedback devices

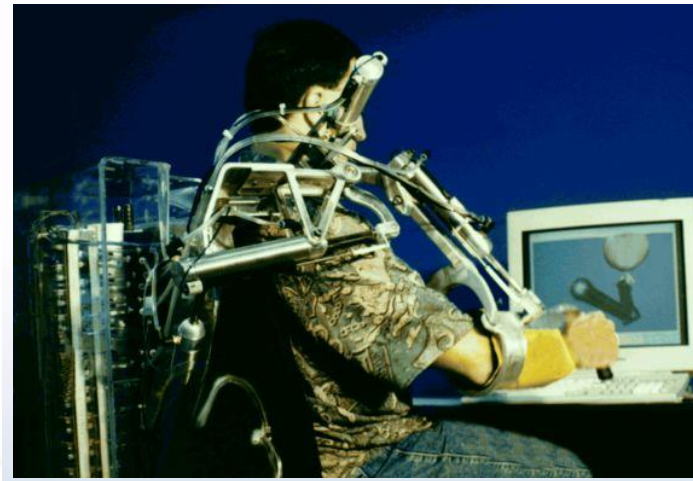


University of Tsukuba

IWATA Lab's HapticMaster

PHANTOM by

SensAble Technologies

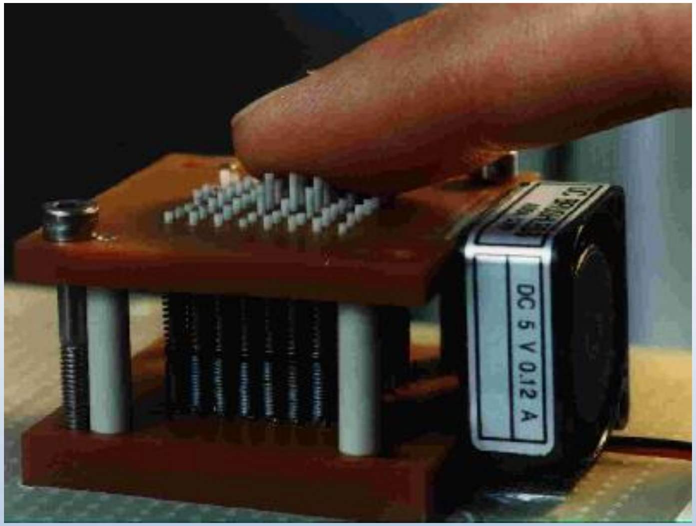


Southern Methodist University, Pneumatic Haptic Interface

Virtual Technologies, Cybergrasp force feedback glove

Tactile display devices

University of Tsukuba, FEELEX1 haptic screen

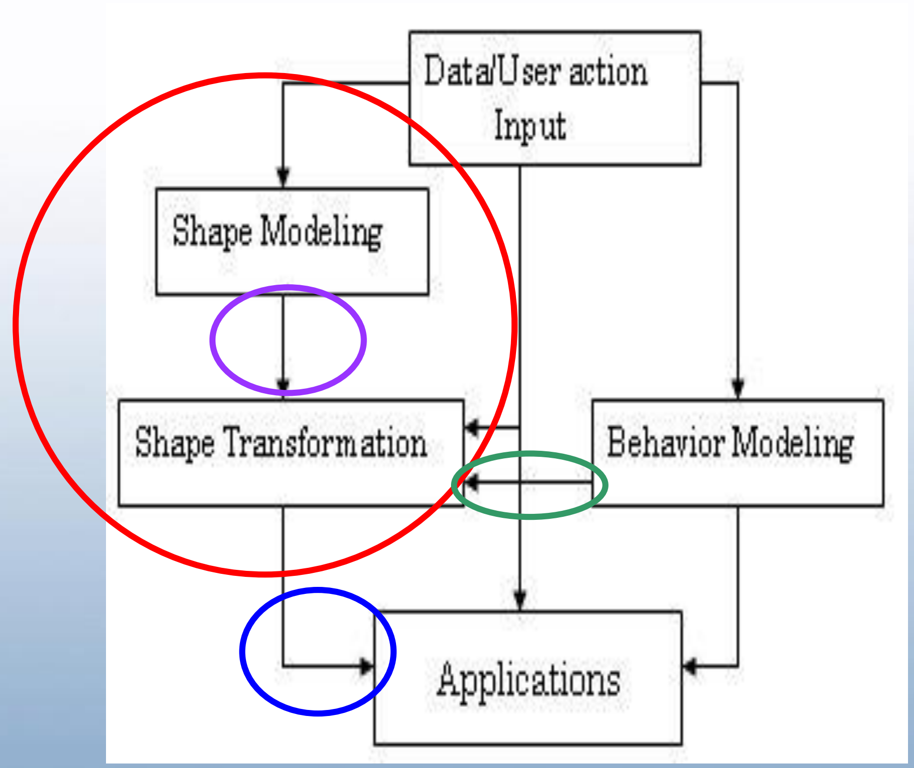


Forschungszentrum Karlsruhe FingPad Tactile Display

iFeel mouse by Logitech

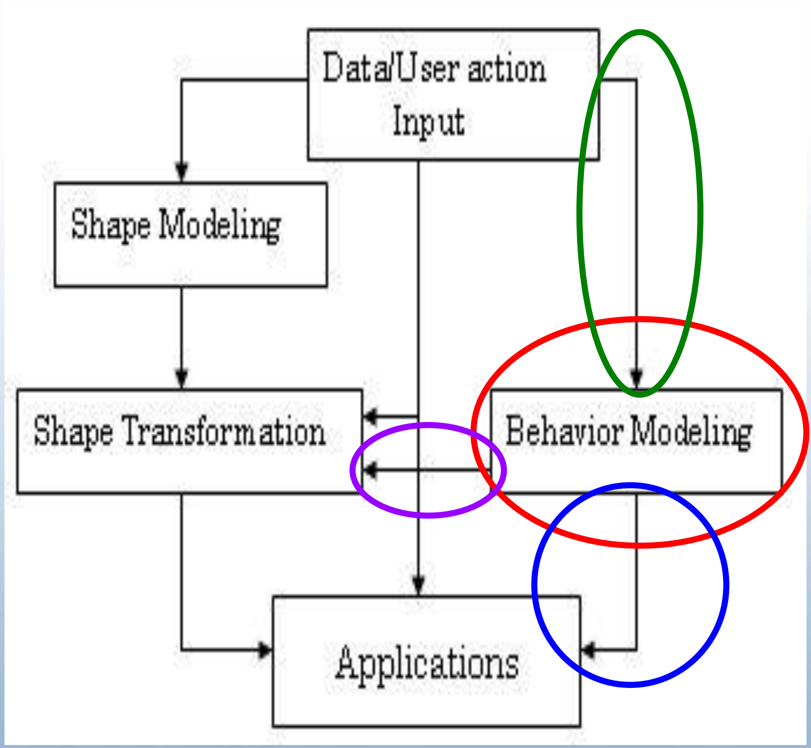
Shape Modelling and Transformations

- Shape models:
  point, curve, surface, solid, volume, N-D
- Shape transformations:
  scale, shift, rotate, deformations, metamorphosis, etc.
- Transformations are predefined or generated from behavior rules



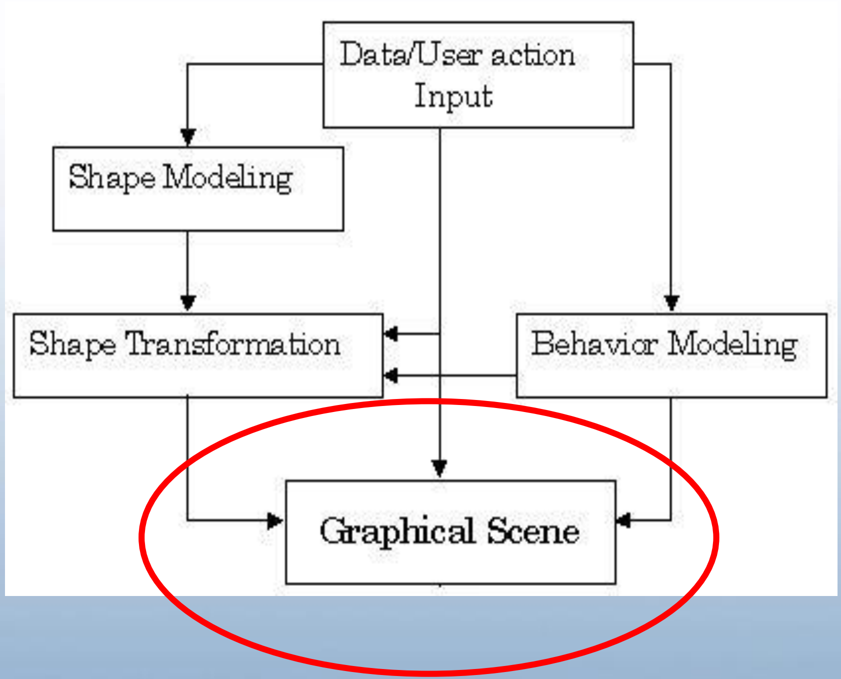
Behavior Modelling

- Behavior rules are generated using input data
- Shape transformations are generated for character motion
- Camera motion in the graphical scene can be generated (fish view)



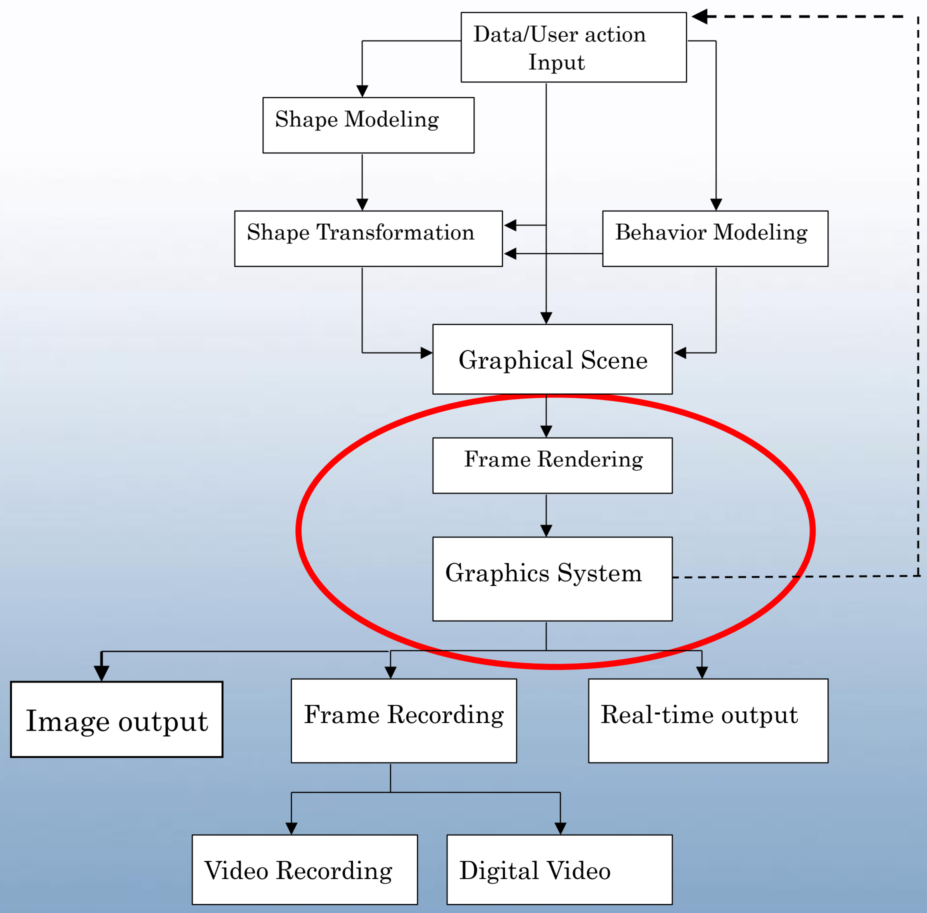
Graphical Scene

- Shapes with transformations
- Visual attributes of objects: color, transparency, texture, etc.
- Bounding boxes
- Light sources
- Camera: position, orientation, motion, etc.
- Background



Rendering and Graphics

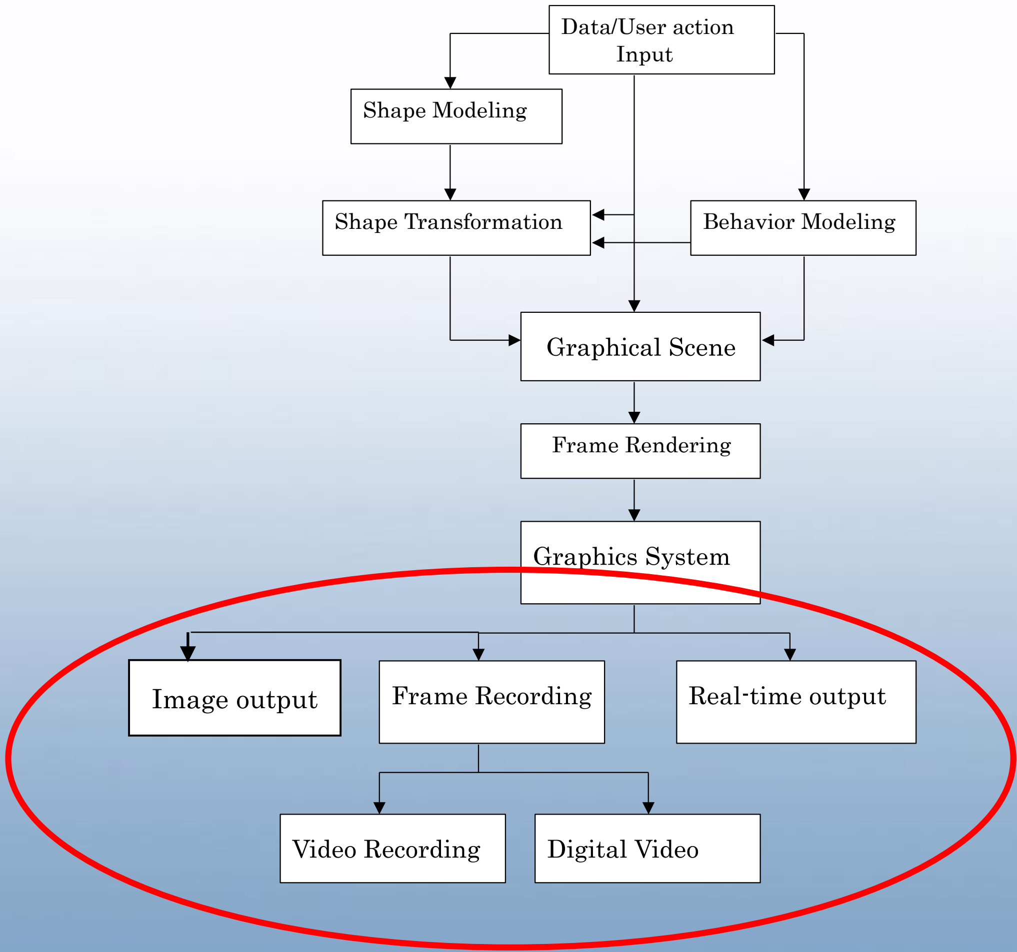
- Rendering:
  - ray-tracing
  - polygonization
  - volume rendering



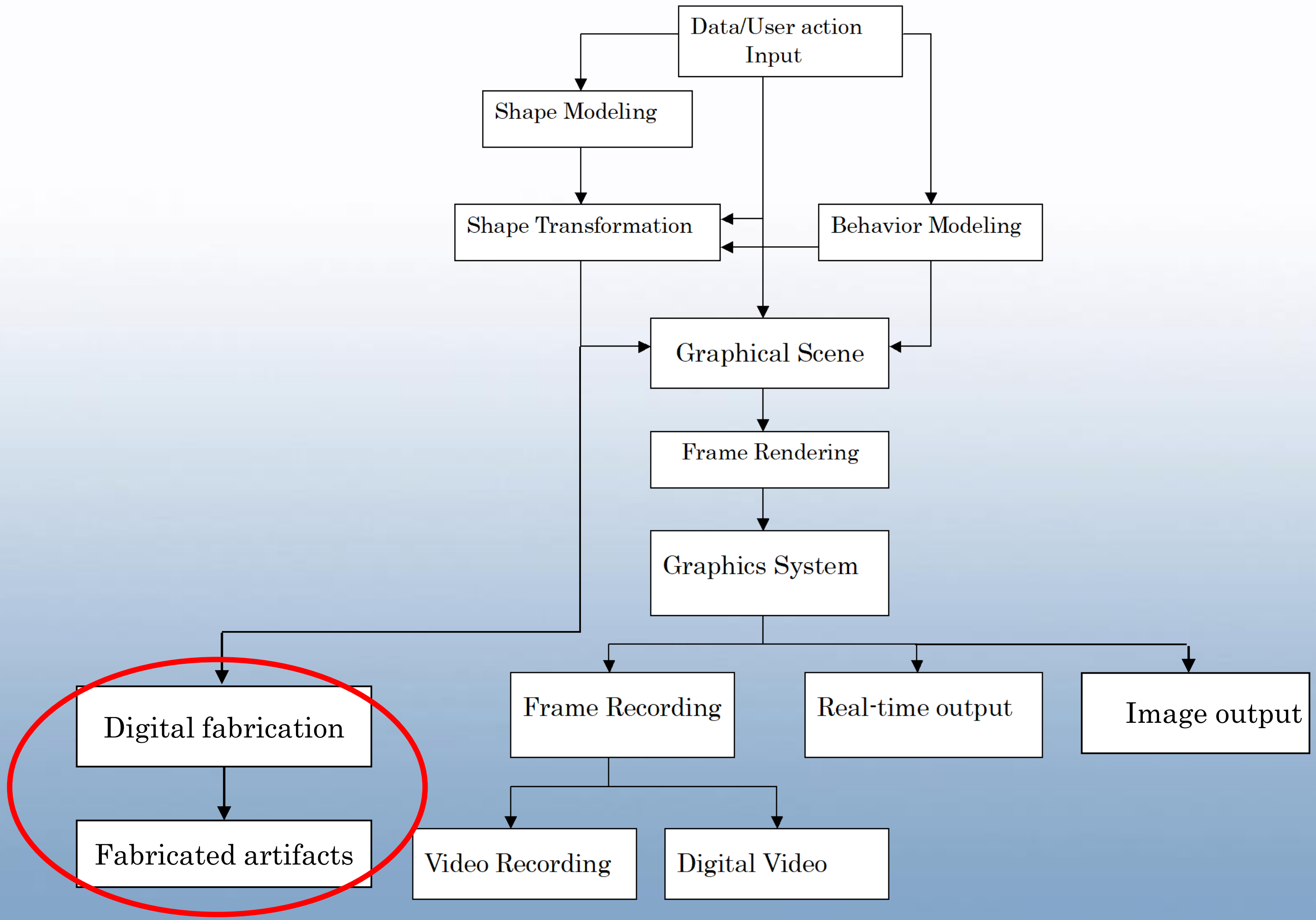
- Graphics system:
  - graphics output
  - animation output
  - interactive input

Graphics and Animation Output

- Single frame animation: recording to video or digital format
- Real-time animation: output to display screen, head-mounted displays, 3D display, etc.



Digital fabrication



Digital fabrication means production of physical objects on the base of computer models and under computer control.

It includes rapid prototyping using large expensive industrial equipment.

Augmented Sculpture Project

SLA 3500

3D Systems

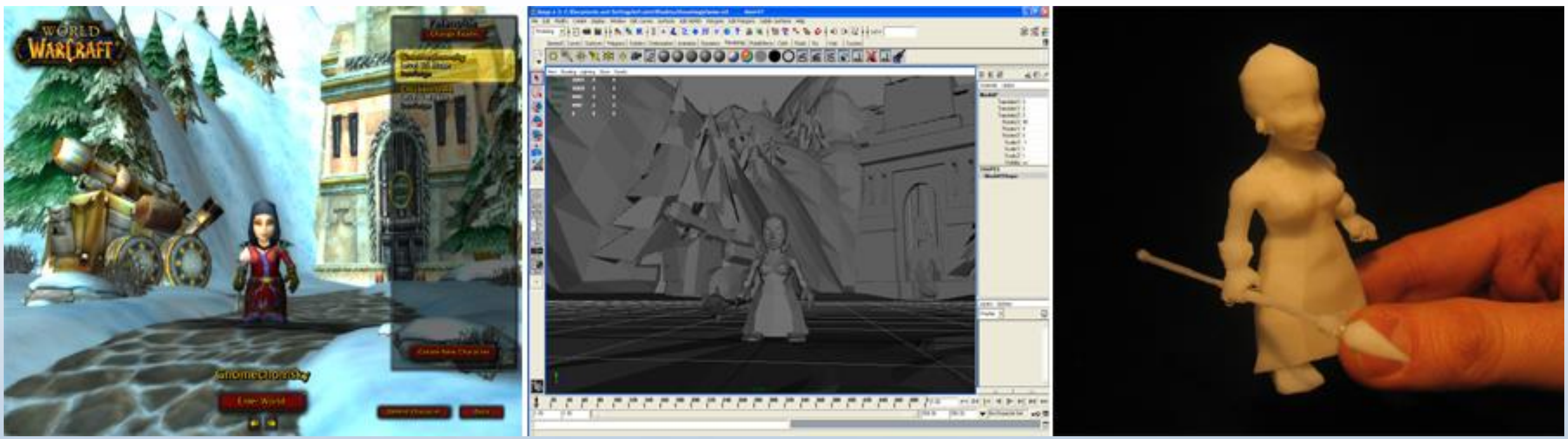
“Plasticity 3”
Bronze (1990)

Digital fabrication includes emerging personal fabrication with inexpensive desktop “3D printers” and “3D plotters”.

Modela MDX-20 by ROLAND DG, Japan

3D-printing a game character

[Eyebeam R&D](http://ogle.eyebeamresearch.org/)
http://ogle.eyebeamresearch.org/



OGLE (**O**pen**GLE**xtractor) is a software package that allows for the capture and re-use of 3D geometry data from 3D graphics applications. The primary motivation is to re-use the 3D shapes we see and interact with in our favorite 3D applications. Digital fabrication technologies make it possible to automatically instantiate 3D objects in the real world.

Key points to remember

- Shape Modelling as an umbrella area for newly emerging shape models.
- Central place of Shape Modelling in various research and application areas.
- Necessity of a shape modelling system as a core for any application system, dealing with digital media.

References

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