FACULTY OF ENGINEERING AND ARCHITECTURE

E016712: Computer Graphics

Introduction

Lecturers: Aleksandra Pizurica and Danilo Babin

GHENT UNIVERSITY

Overview

- Lectures and coursework
  - Instructors, projects, exercises, exam,…
- Contents of this course
  - Topics, syllabus, books
- Computer graphics around us
  - Why is it interesting? Applications
- Interesting to know
  - About 3D modelling

Lectures and Coursework

Course Staff

Lecturers

- Prof. Aleksandra Pizurica and Dr. Danilo Babin
- Email: aleksandra.pizurica@ugent.be; danilo.babin@ugent.be
- Office: Technicum, Sint-Pietersnieuwstraat 41, Department **TELIN**
- Research groups

  GAIM – Group for Artificial Intelligence and Sparse Modelling (A. Pizurica)

  IPI – Image Processing and Interpretation (D. Babin)

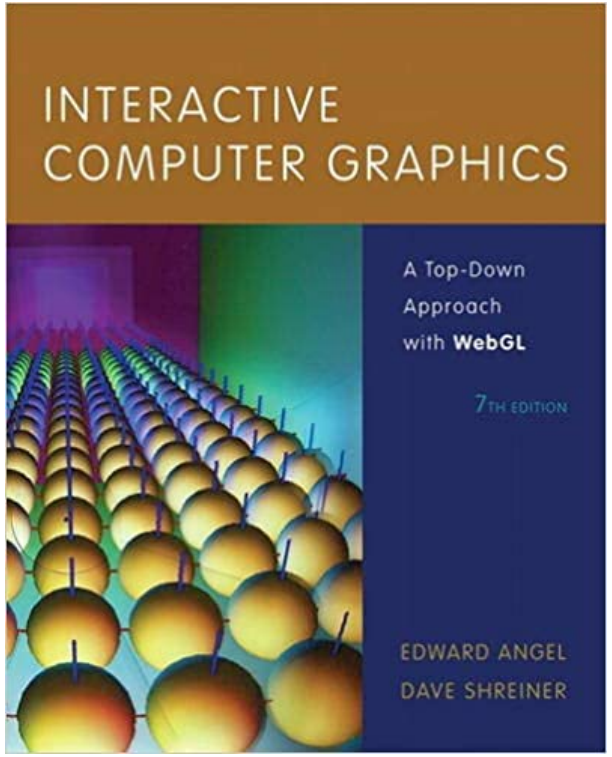
Assistant: Michiel Vlaminck Michiel.Vlaminck@ugent.be

Aleksandra Pizurica

Danilo Babin

Michiel Vlaminck

Study material



Recommended book:

Edward Angel and Dave Shreiner,

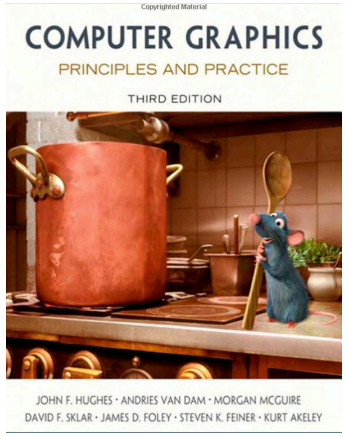
Interactive Computer Graphics:
A Top-Down Approach with WebGL

Pearson, 2014.

Denoted in the slides as [A&S]

A selection of articles, slides from the lectures and some slide notes will be available via Ufora.

Other useful books & material



J. F. Hughes, A. van Dam, M. McGuire, D. F. Sklar,
J. D. Foley, S. K. Feiner and K. Akeley:

Computer graphics: Principles and practice (3rd ed.)

Addison-Wesley Professional, 2013.

Getting started with OpenGL, WebGL, Three.js:

- **SIGGRAPH 2018 Tutorial** - Edward Angel, Eric Heines and Dave Shreiner: *Getting started with WebGL and Three.js* (slides, notes and code available at: https://www.cs.unm.edu/~angel/SIGGRAPH18/COURSE/EXAMPLES/
- **SIGGRAPH 2017 Tutorial** - Edward Angel and Dave Shreiner: *Application Development with WebGL* slides, notes and code available at: https://www.cs.unm.edu/~angel/SIGGRAPH_ASIA_17/
- **SIGGRAPH 2013 Tutorial** - Edward Angel and Dave Shreiner: *An Introduction to OpenGL Programming* (slides, notes and code available at: http://www.cs.unm.edu/~angel/SIGGRAPH13/)

Main journals and conference

Some of the representative Computer Graphics Journals:

- ACM Transactions on Graphics (TOG)
- Computer Graphics Forum (CGF)
- IEEE Transactions on Visualization and Computer Graphics (TVCG)
- IEEE Computer Graphics and Applications (CG&A)

Conferences

- ACM SIGGRAPH
- IEEE VIS : Conference on Scientific Visualization, Information Visualization and Visual Analytics

Projects

- Project supervision:
  - D. Babin Danilo.Babin@ugent.be
  - M. Vlaminck Michiel.Vlaminck@ugent.be
- Programming assignment and theoretical insight
  - Not (fully) covered in the lectures (you will read an article)
  - You will produce: code + short report
  - Try to go beyond and make something cool!
- Done in groups (2 or 3 students per group)
  - Team work, but everyone participates fully!
  - Understanding and the work done tested individually
  - Contact your assistants timely for advice and help
- OBLIGATORY must be passed in order to pass the final exam

Projects: what we expect

- Collaboration encouraged, but contributions from each student are requested and must be evident
- Writing the code
  - Write your own code and give your own comments
  - Using example codes (if you find these) allowed, but reference them
  - Pay attention to the efficiency of the code
- Writing report:
  - Write the text yourself
  - You can cite a sentence form other work, but reference it
  - Never copy large parts of the text from other sources!
- Creativity and original contributions
  - Be free to extend the project assignment further yourself in any way you find it interesting (in the code functionality, theoretical insight,…)

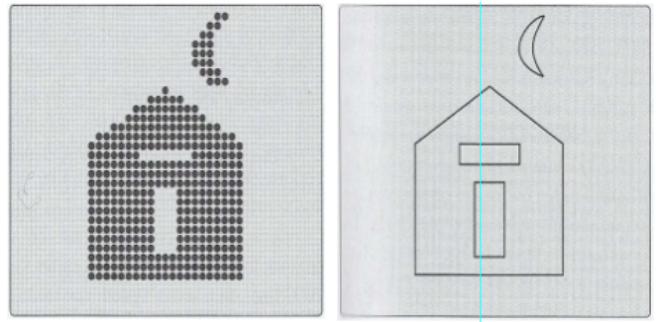
Evaluation

- Written exam (2/3)
  - Theory (closed book)
  - Problem solving (open book)
- Project, group work (1/3)
  - Literature study, solving a concrete task, creative development, programming
  - Written report
  - Demonstration of the code and discussion

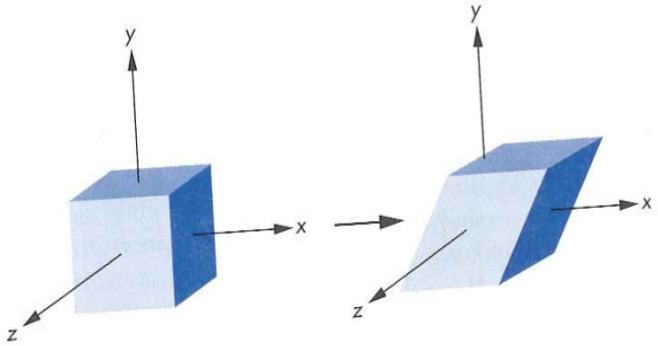
Contents of this course

Contents…

- Digital images and graphics formats
  - Raster images
  - Vector images
  - Elements of color perception and reproduction



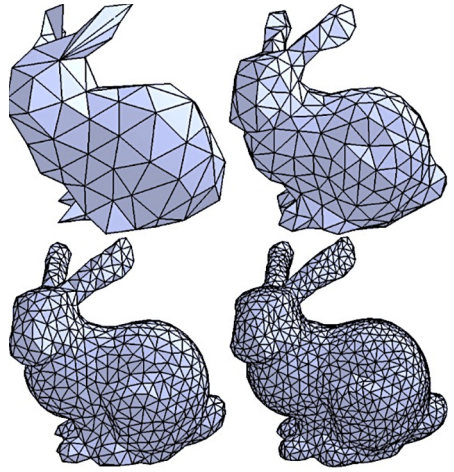
- Geometrical transformations
  - Homogeneous coordinates
  - Matrix representation and composition of 2D and 3D transformations
  - Quaternions



…Contents…

- Meshes
  - Mesh generation
  - Mesh subdivision strategies

    Delaunay, Graph cuts, Least squares

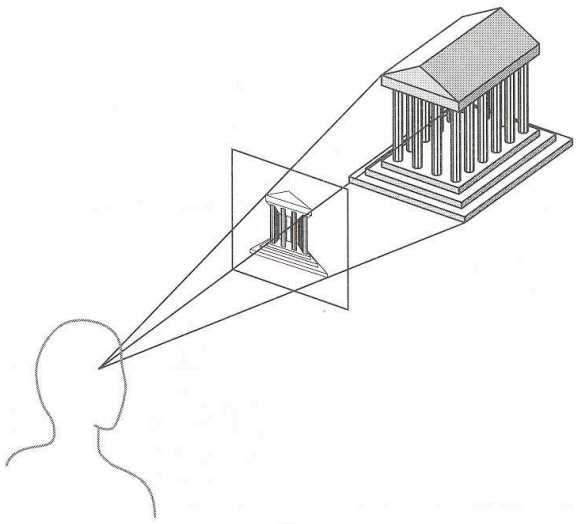


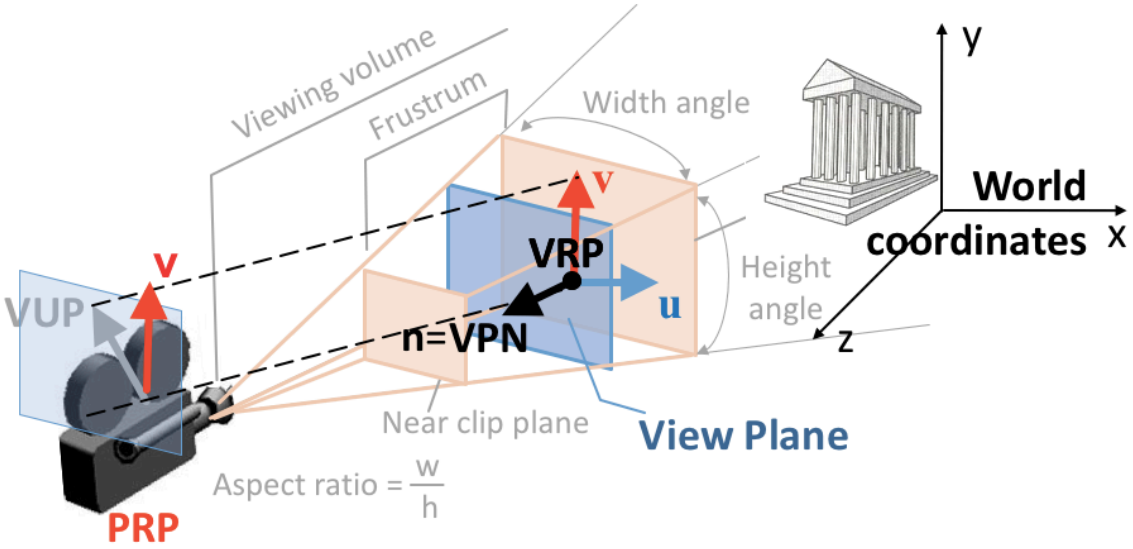
- Point clouds & scene graphs
  - Point clouds generated by LiDAR
  - Point cloud meshing
  - Scene graphs

    Octree, K-d tree, BSP tree

…Contents…

- Viewing in 3D
  - Classical and computer viewing
  - Projections (parallel and perspective)
  - Clipping in 3D
  - Hidden surface removal
  - Synthetic camera model





…Contents …

- Texture synthesis
  - Model-based (statistical approaches)
  - Image quilting
  - Wang tiles

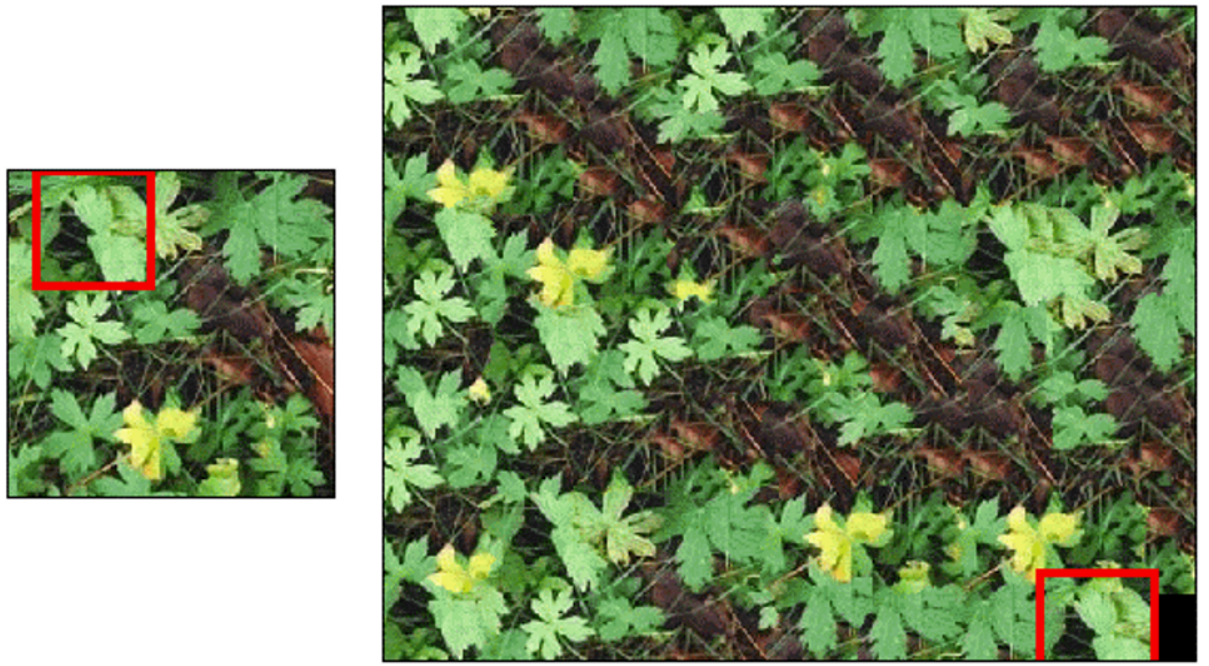
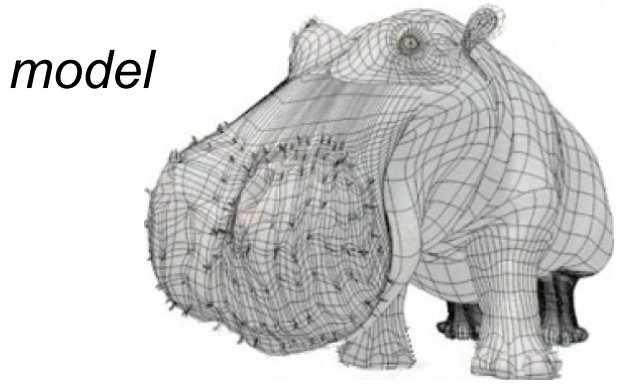


Image quilting. Source: https://en.wikipedia.org/wiki/Texture_synthesis

…Contents …

- Illumination and shading
  - Illumination models
  - Shading models for polygons
  - Ray casting and ray tracing
  - Radiosity



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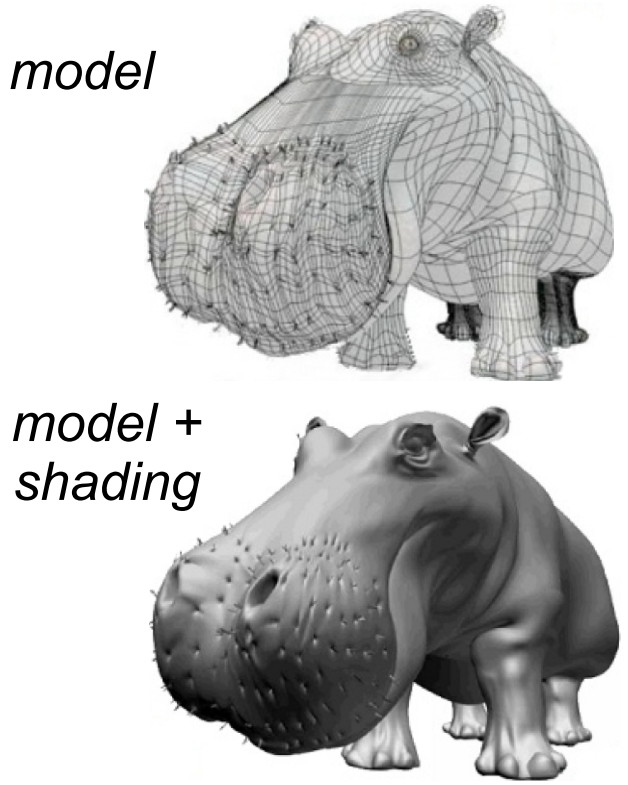
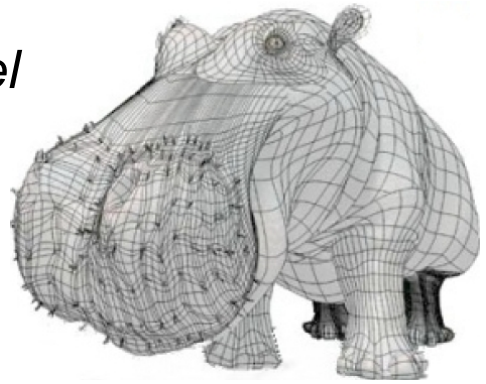


…Contents …

- Illumination and shading
  - Illumination models
  - Shading models for polygons
  - Ray casting and ray tracing
  - Radiosity

- Texture generation and mapping
  - Texture generation:
    - statistical methods
    - tiling methods
  - Texture mapping

model



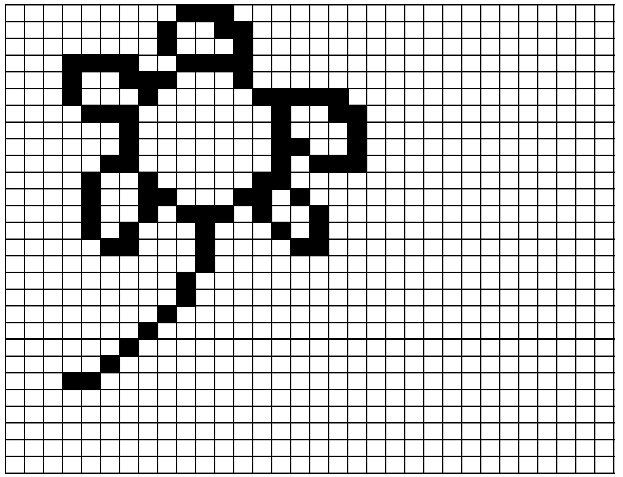
model + shading

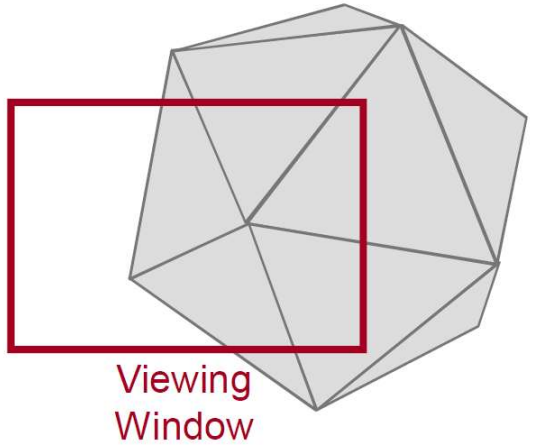
model + texture + shading

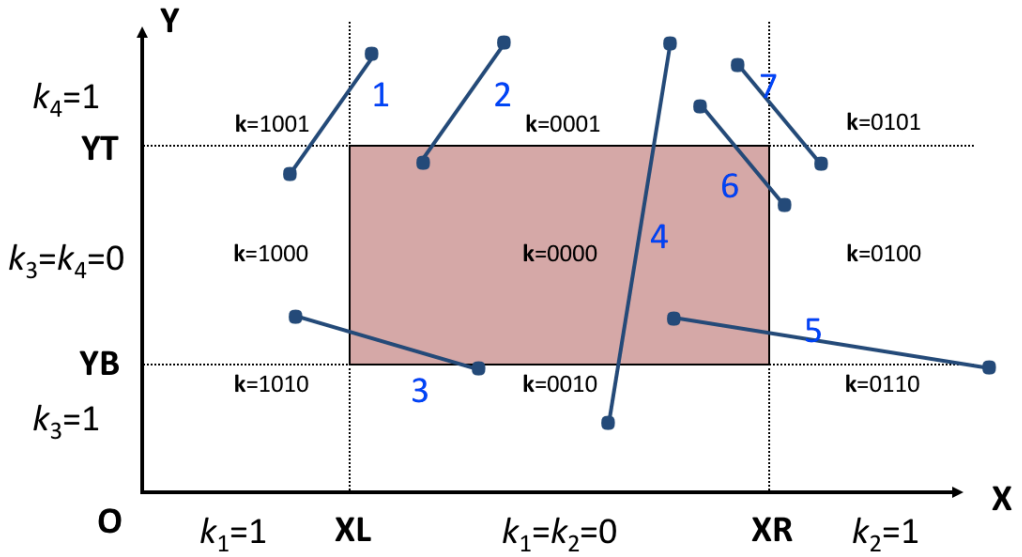
...Contents....

(only 6-credits version)

- Rasterization and clipping
  - Scan conversion
  - Polygon filling
  - Visibility determination
  - Clipping



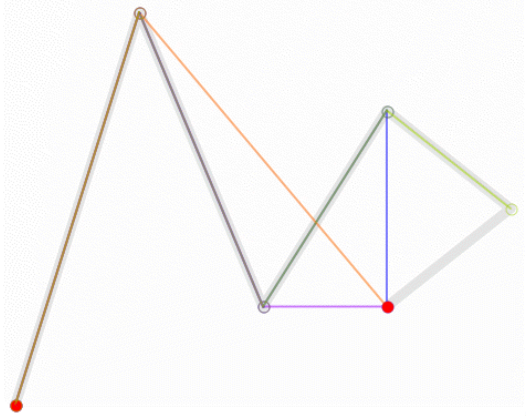


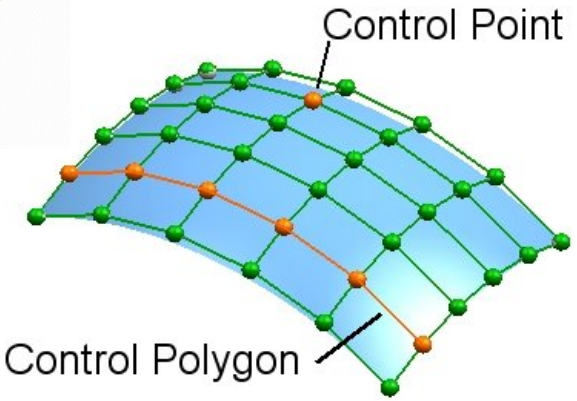


...Contents...

(only 6-credits version)

- Curves and surfaces
  - Polynomial forms
  - Hermite curves and surfaces
  - Bézier curves and surfaces
  - Non-uniform rational B splines (NURBS)
  - Splines
  - Subdivision surfaces

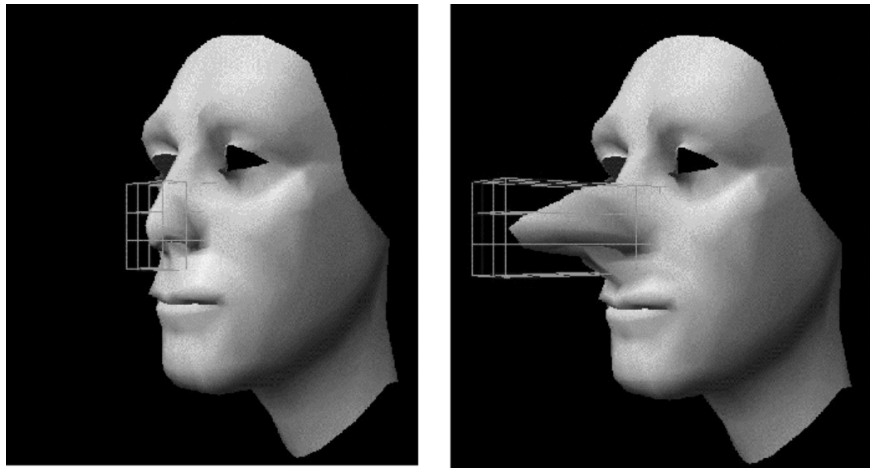




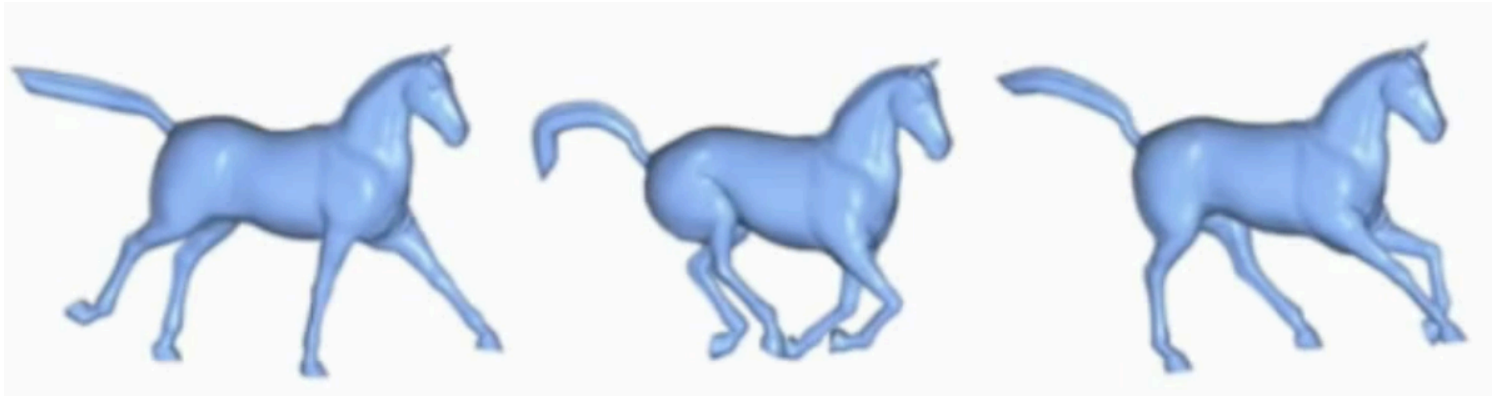
...Contents...

(only 6-credits version)

- Introduction to animation
  - Key frames
  - Forward and inverse kinematics
  - Hierarchical kinematics
  - Dynamics



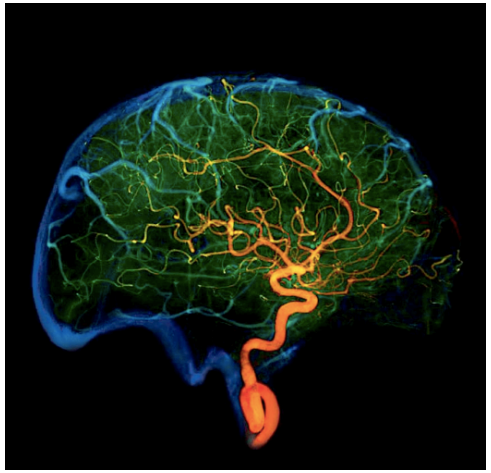
- Animation approaches
  - Motion capture
  - Free form deformation
  - Level sets
  - Skeletons, boids, particle systems

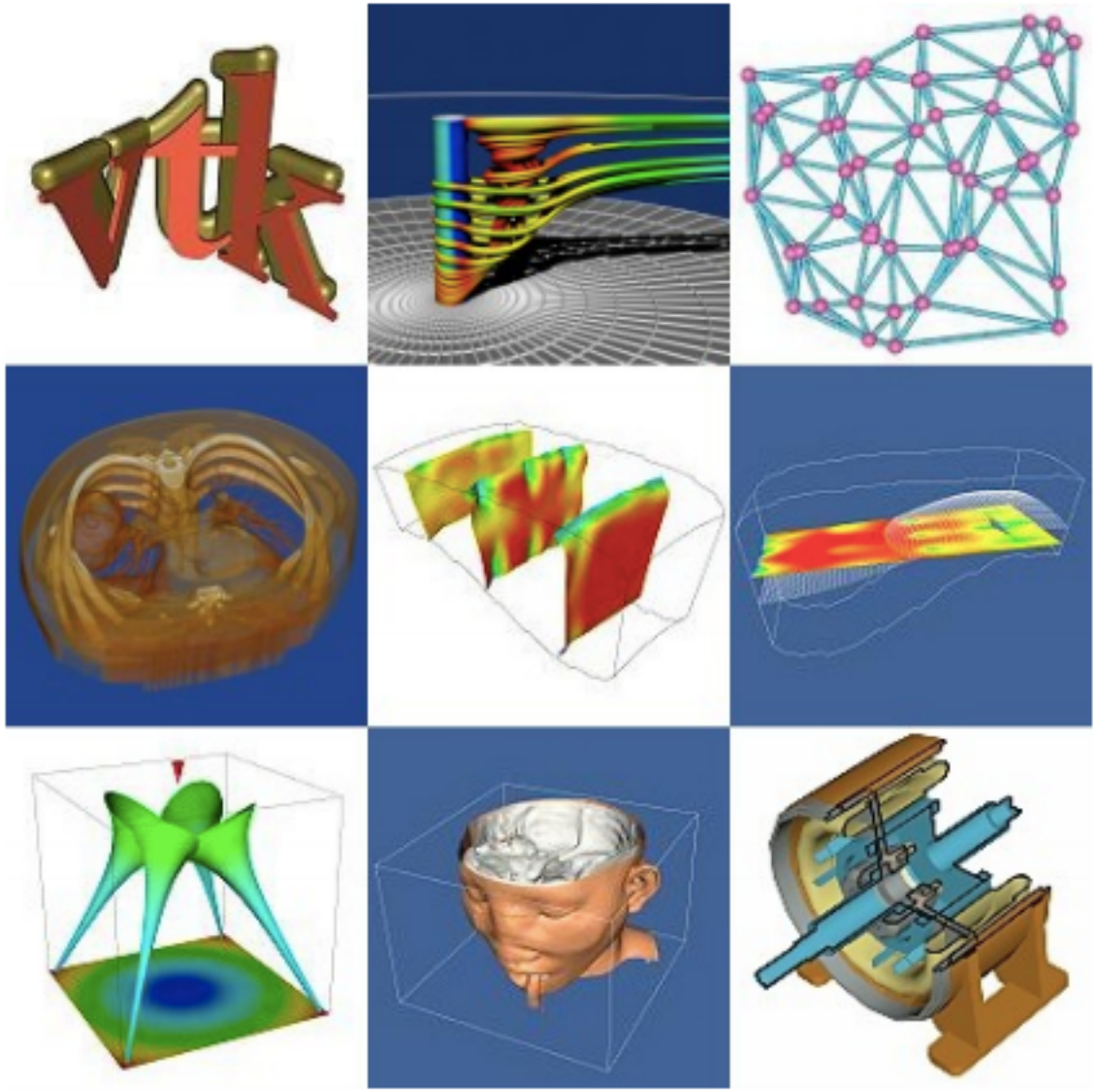


...Contents...

(only 6-credits version)

- Medical image visualization
  - Visualization toolkit (VTK)
  - Multi-plane reconstruction
  - Surface rendering (marching cubes)
  - Volume rendering

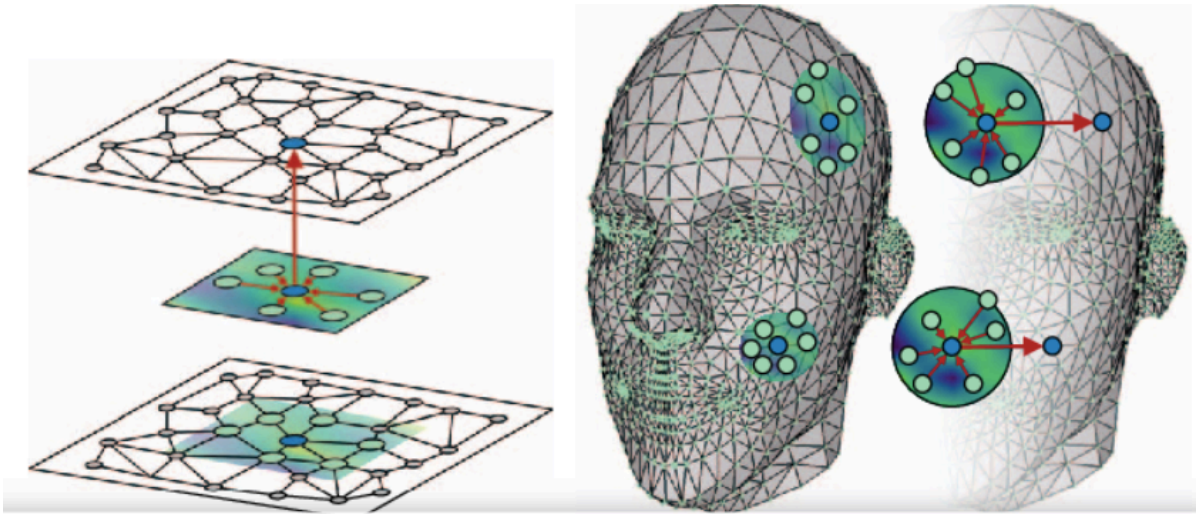




...Contents

(only 6-credits version)

- Advanced topic
  - Deep learning in computer graphics
  - Elements of Geometric deep learning
    - Extending deep learning models to non-Euclidean data like point clouds



Links with image processing

- Image processing → improve and analyze image content
  - Improving image quality (noise removal, sharpening,…)
  - Analyzing image (and video) content:
    - detecting and recognizing certain patterns (e.g. characters), segmenting (and tracking in time) objects of interest,…
  - Scene analysis (recognize and reconstruct a 3D model of a scene from 2D images)

Links with image processing

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  - Scene analysis (recognize and reconstruct a 3D model of a scene from 2D images)
- Computer graphics → synthesize images from computer models
  - Display of information
  - Design of 2D and 3D objects
  - Animation
  - User interfaces
- Overlap between the two domains is growing

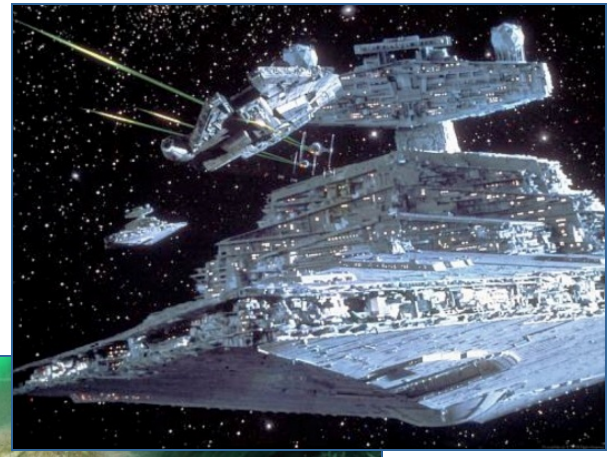
Computer Graphics around us

Applications of Computer Graphics

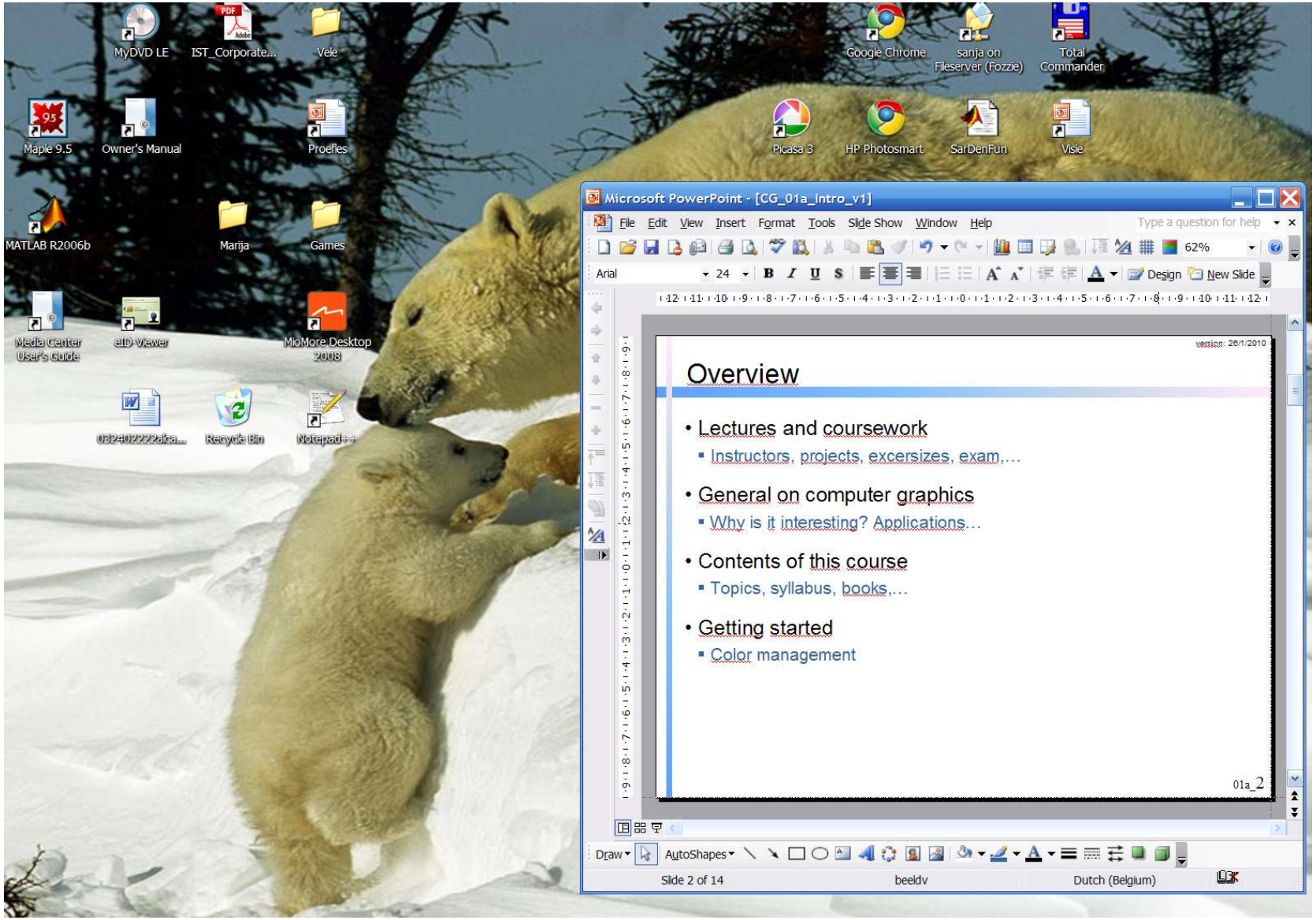
- Entertainment
- Graphical user interface (GUI)
- Computer-aided design
- Scientific visualisation
- Education and training
- Computer art
- Analysis of artworks
- Virtual reality (virtual meetings, virtual visits to museums,…)
- …

Applications: Entertainment

- Movies
- Computer games

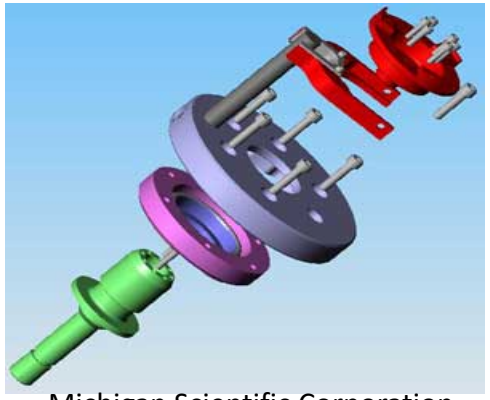


Applications: Graphical User Interface

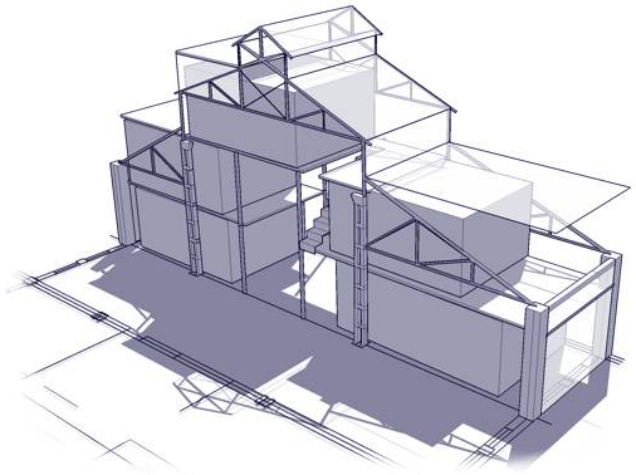


Applications: Computer Aided Design

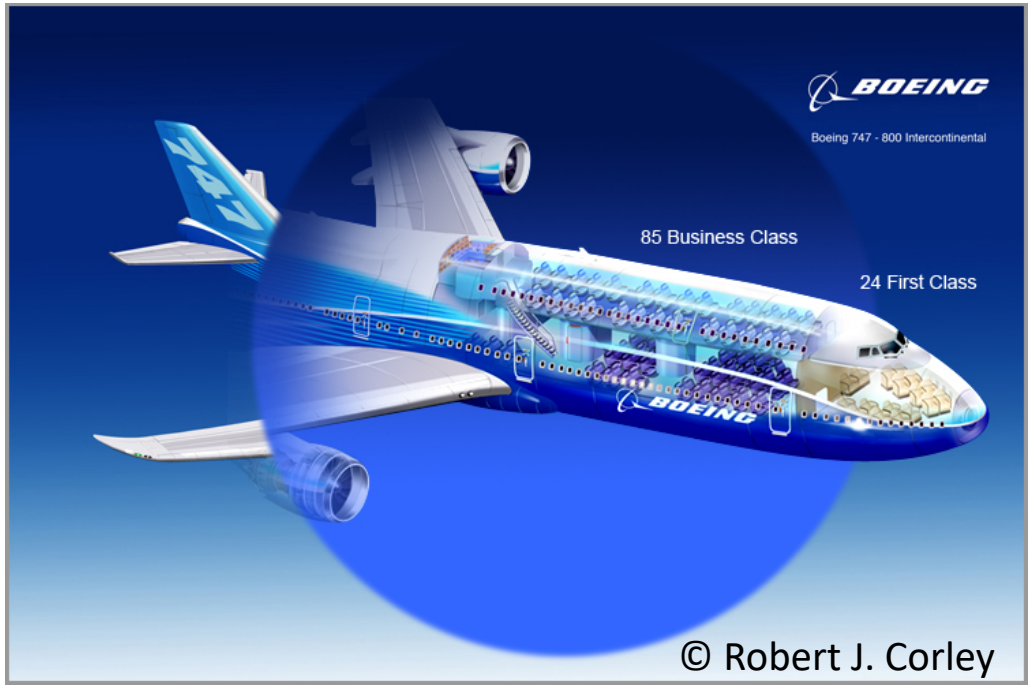
- Designing objects (real or virtual), 2D or 3D
- Mechanics, architecture, GIS,…
- Examples: AutoCAD, GoogleSketchUp,…



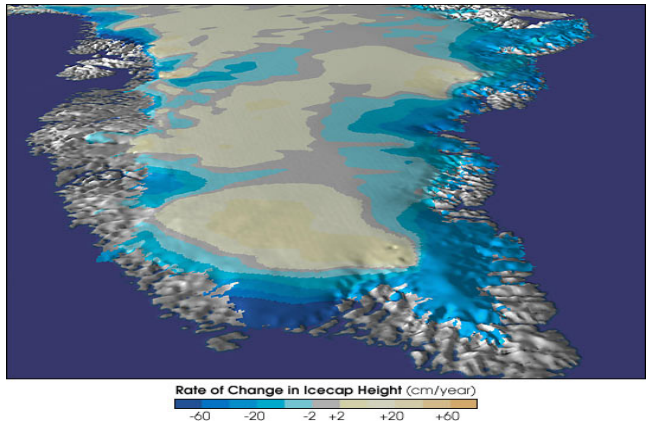
Michigan Scientific Corporation



SketchUp Pro

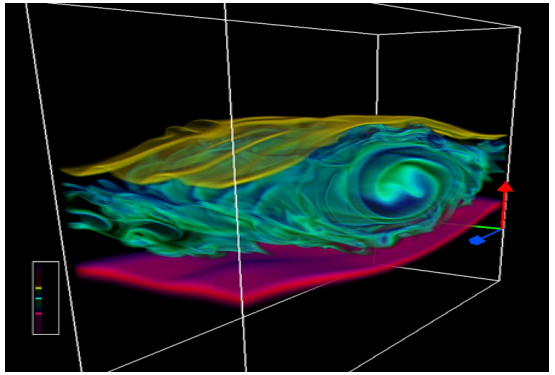


Applications: Scientific Visualisation



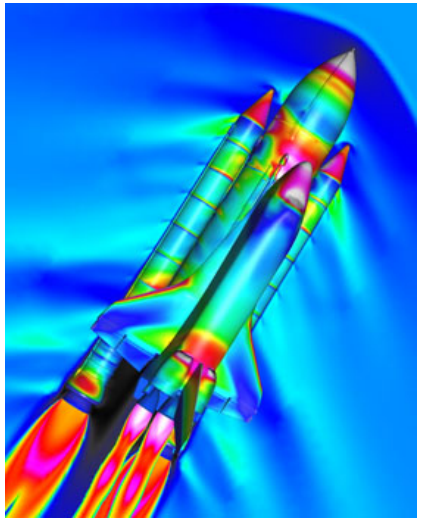
Rate of Icecap change

NASA GSFC Scientific Visual Studio



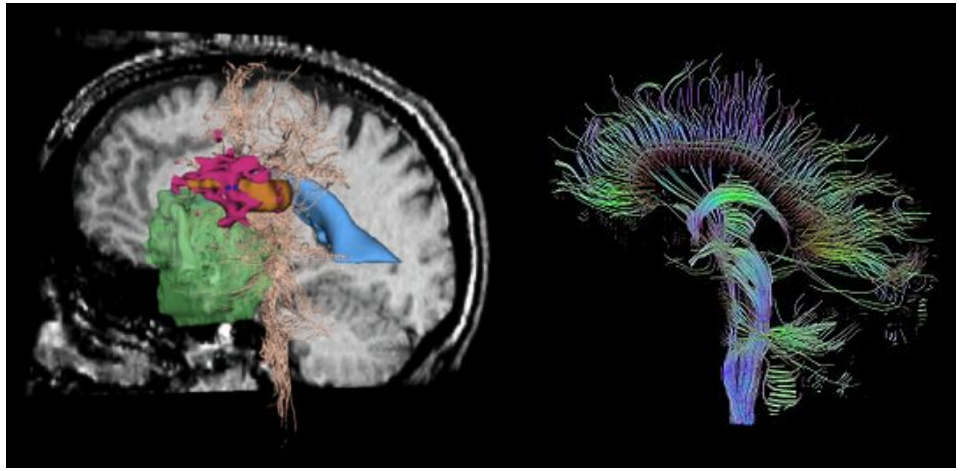
Geo physical turbulence

Benjamin Jamroz, Ed Lee, and Thorwald Stein



A simulation of shuttle pressure

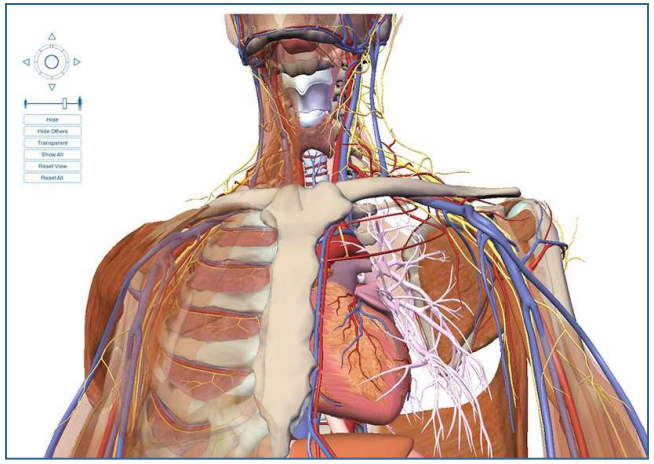
NASA Johnson Space Cemnter



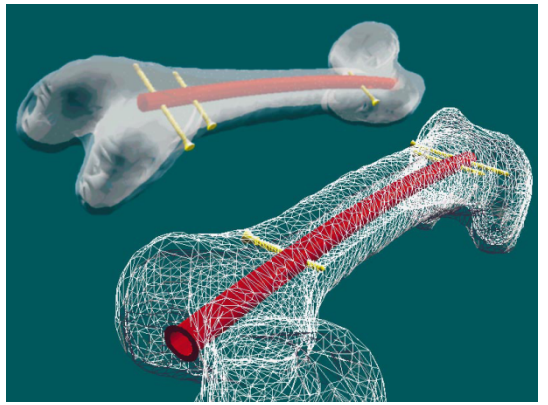
Brain image and estimated neural connections

Neuroimage Analysis Center

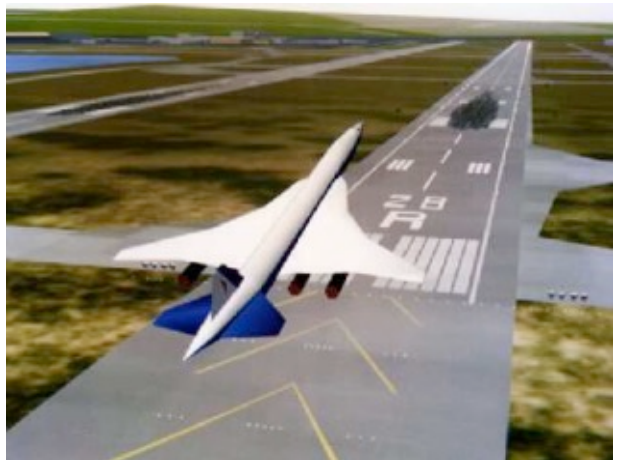
Applications: Education and training



Visible Body
Argosy Publishing



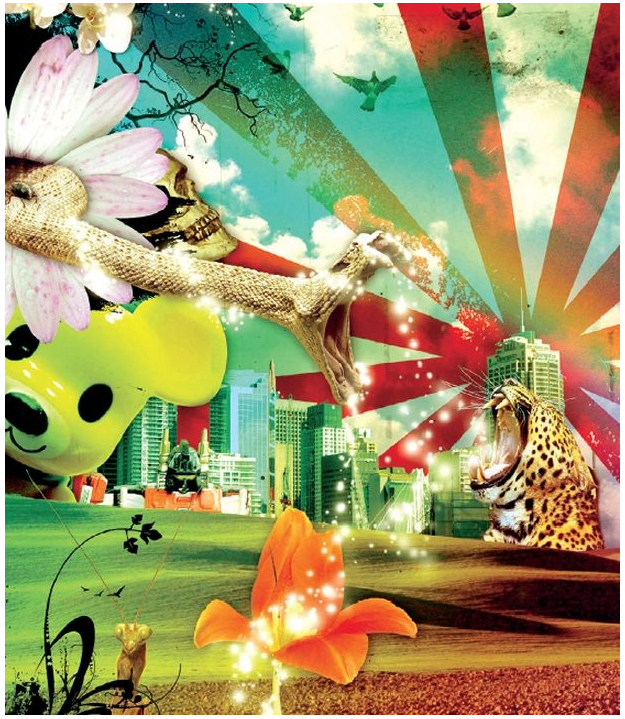
Virtual Orthopedic Surgery Training
A. Sourin, O. Sourina, and H. Tet Sen
Projects in VR



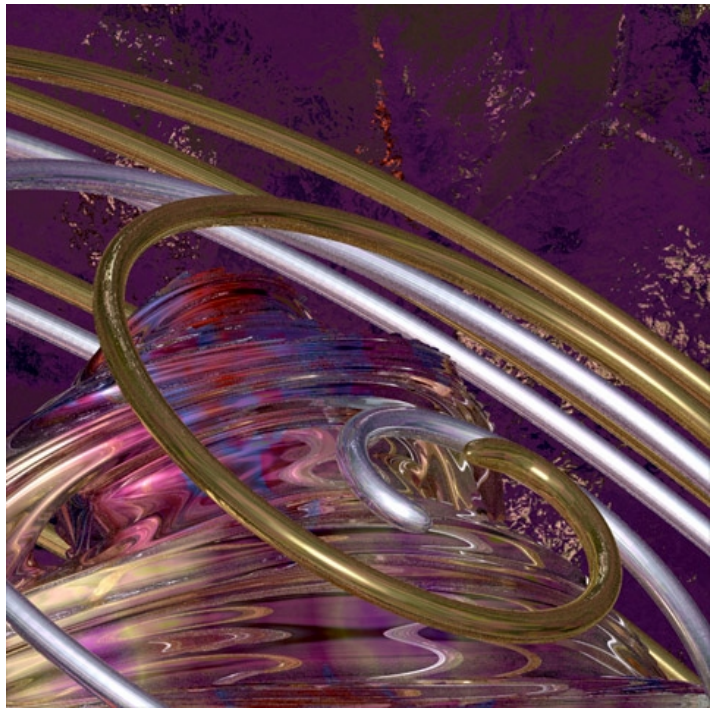
Flight Simulator
NASA

Driving Simulation
Evans & Sutherland

Applications: Computer Art



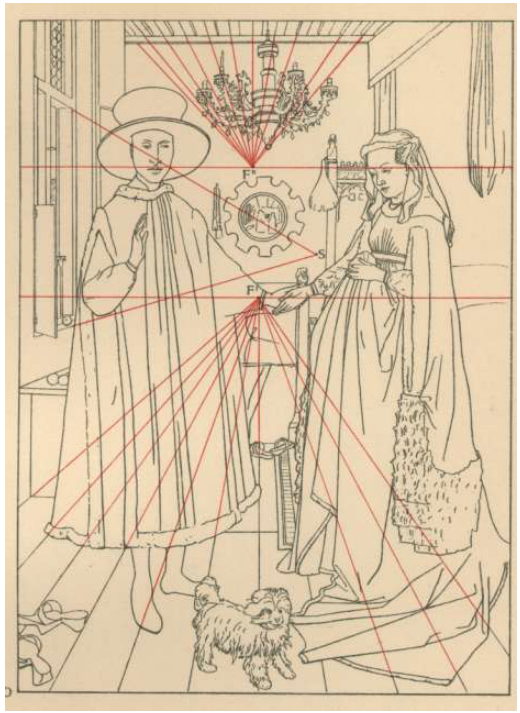
Teis Albers "Animal Conversation"



Robert W. Mc. Gregor

Applications: Analysis of artworks

The Arnolfini Portrait, Jan Van Eyck, 1434



Computer graphics techniques (ray tracing) are used to study the perspective in art works (Is it realistic? Is it “too realistic” (was the artist helped by an optical device)? Where is the light source? etc.)

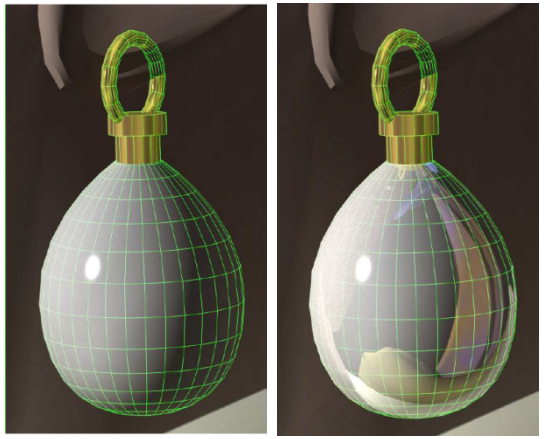
Applications: Analysis of artworks

Girl with a pearl earring
Johannes Vermeer (1632-1675)

- We can generate computer models of objects (e.g., pearls), and "view" them under different lighting conditions.

- We can also generate a 3D model of the whole scene and infer so far unseen views of the scene and persons in it.

Examples from the work of David Stork and collaborators



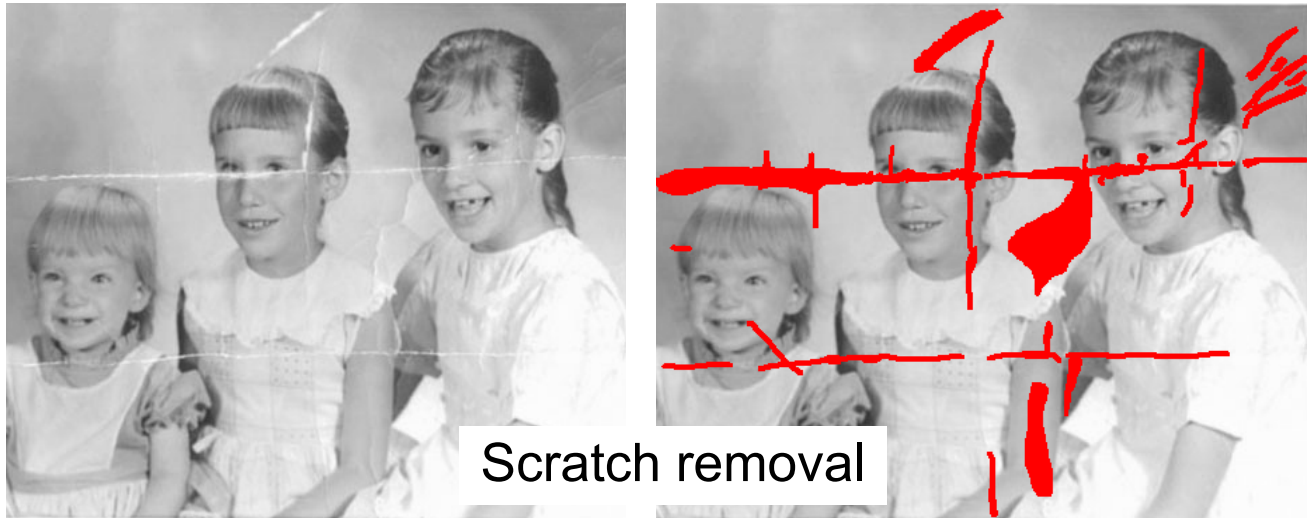
Applications: Virtual reality

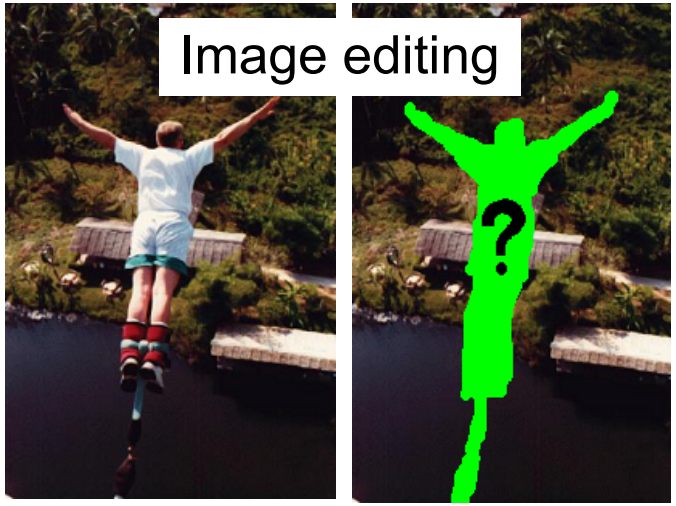
A virtual meeting where people are represented by their avatars

Computer graphics techniques are essential for creating virtual reality worlds, like

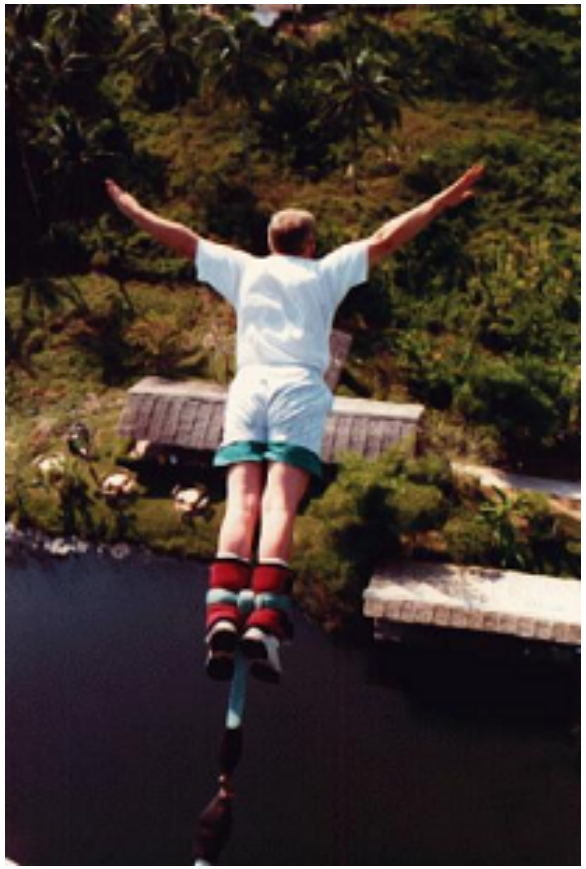
- Future meetings (people represented by their avatars in virtual conference rooms, while sitting comfortably in their homes, remote offices...)
- Virtual city tours, virtual visits to museums,…

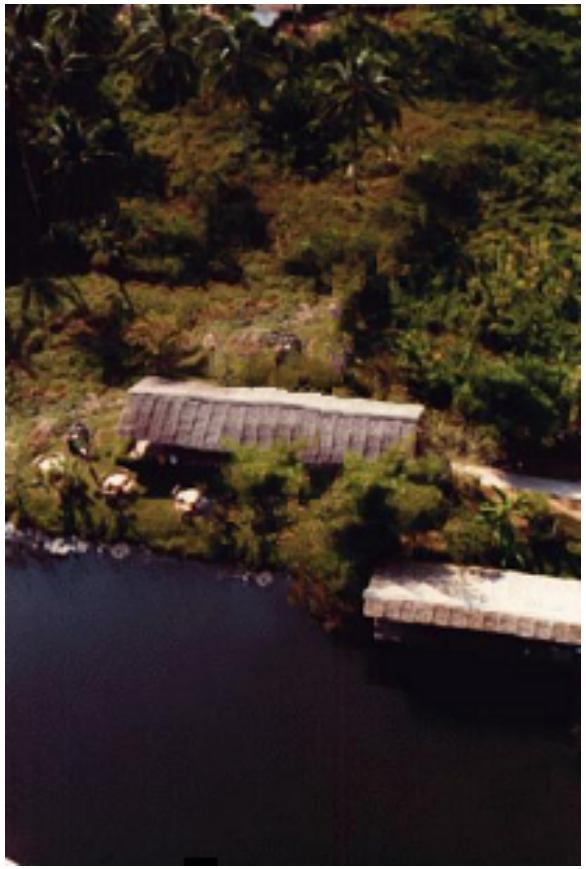
Applications: inpainting



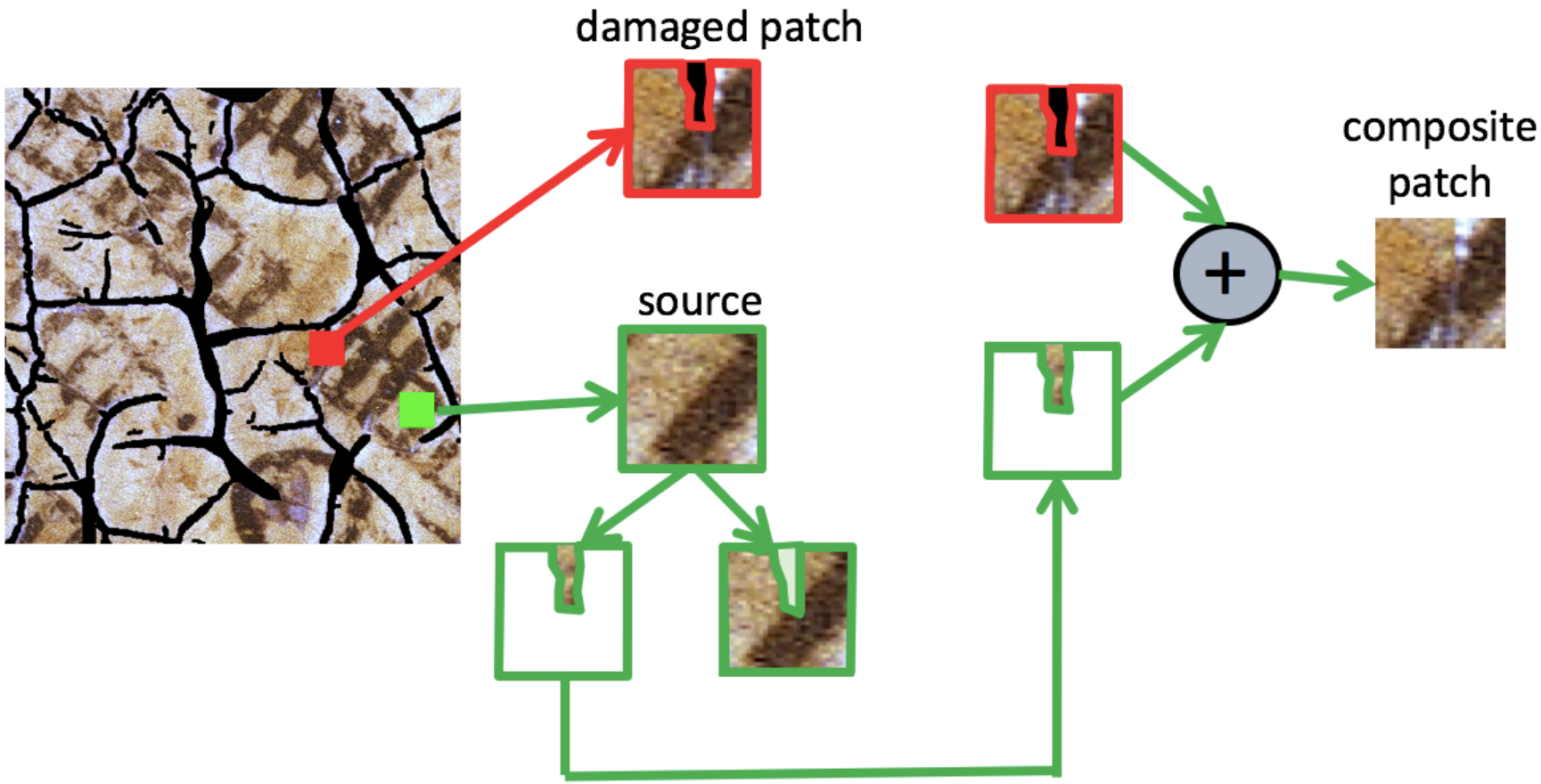


Applications: inpainting (photo editing)

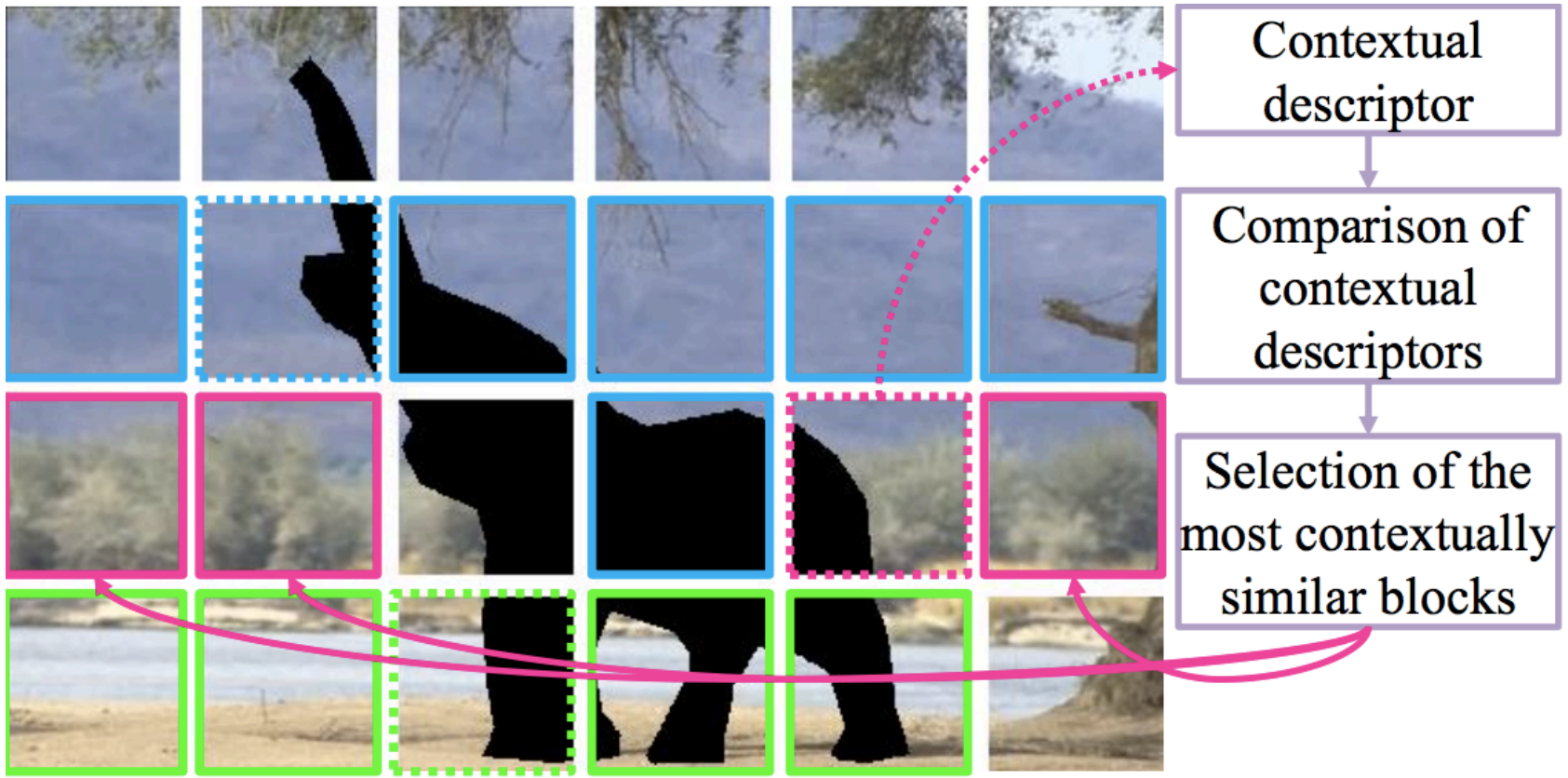




Patch-based inpainting

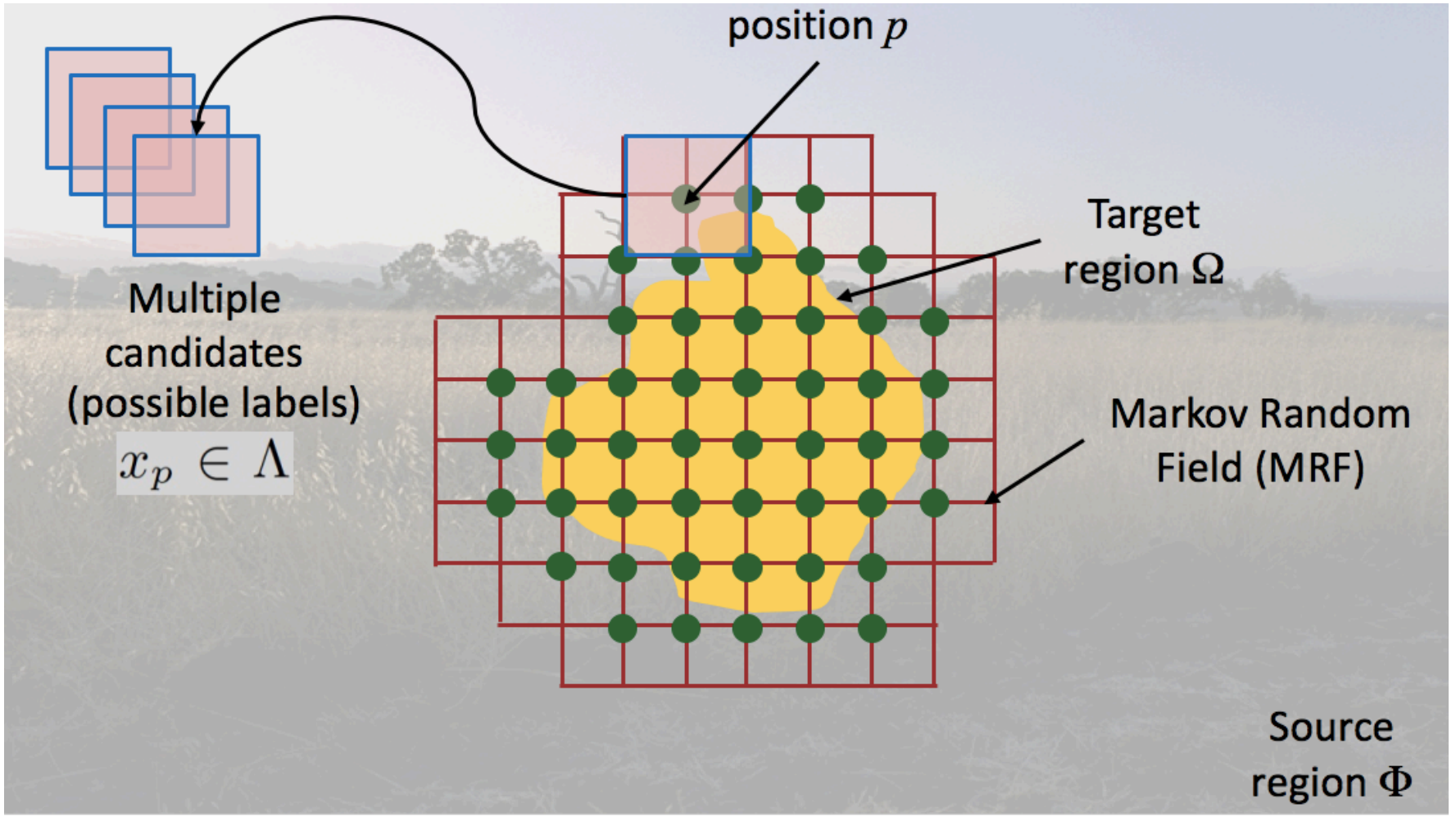


Context-aware inpainting



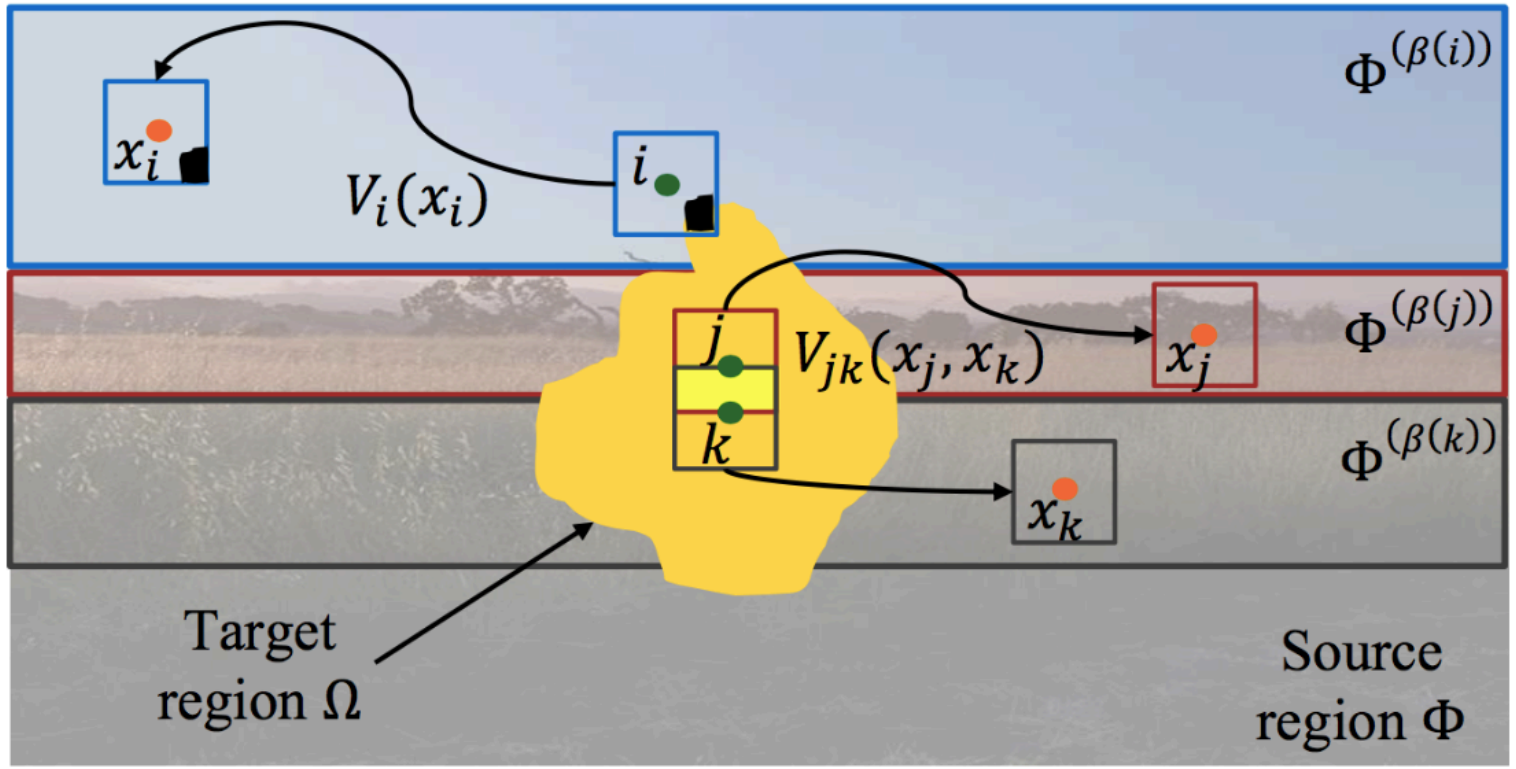
T. Ruzic and A. Pizurica. Context-Aware Patch-Based Image Inpainting Using Markov Random Field Modeling. *IEEE Transactions on Image Processing*, 2015.

Global inpainting



T. Ruzic and A. Pizurica. Context-Aware Patch-Based Image Inpainting Using Markov Random Field Modeling. *IEEE Transactions on Image Processing*, 2015.

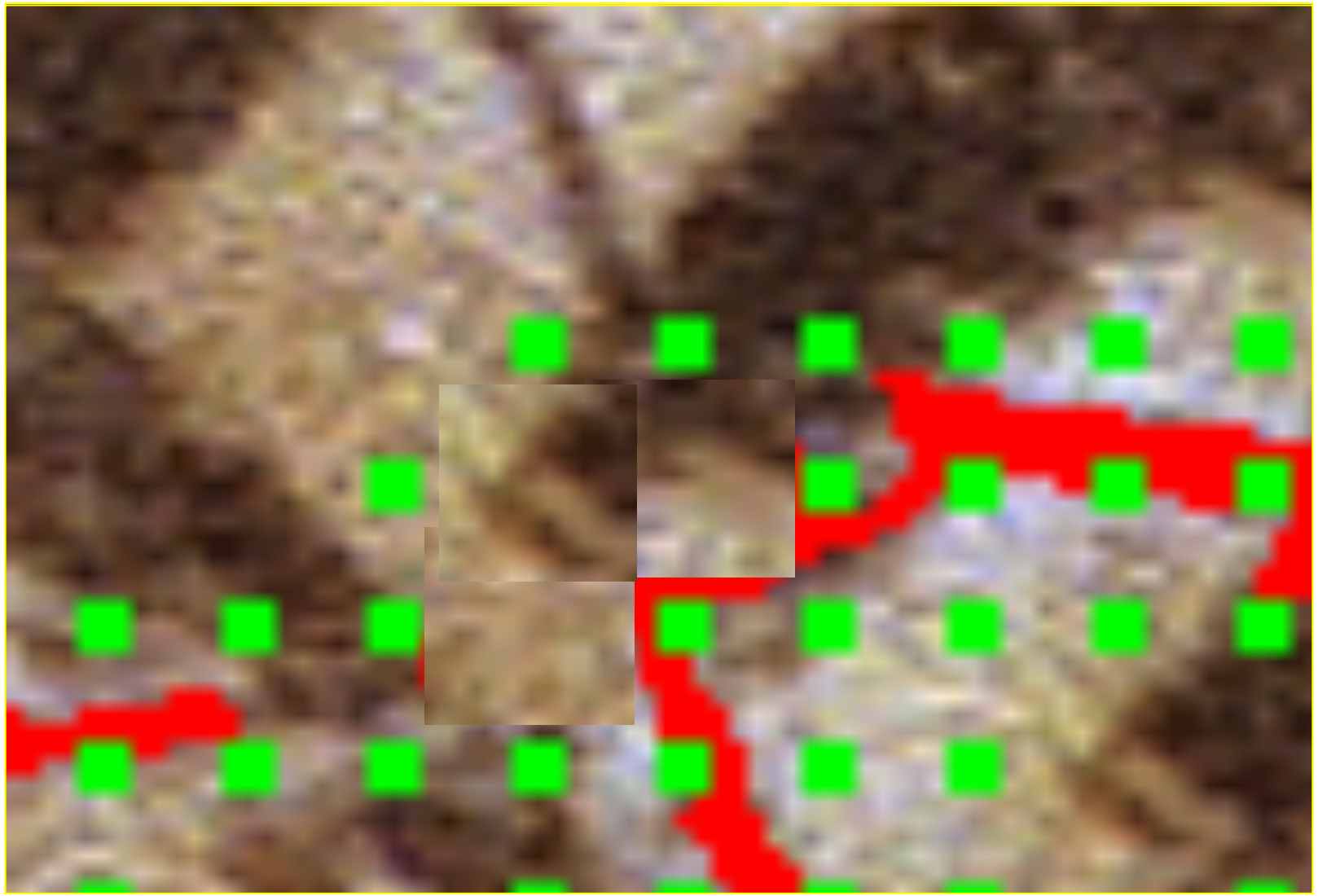
Global inpainting



$$E(\mathbf{x}) = \sum_{i \in \nu} V_i(x_i) + \sum_{\langle i,j \rangle \in \varepsilon} V_{ij}(x_i, x_j),$$

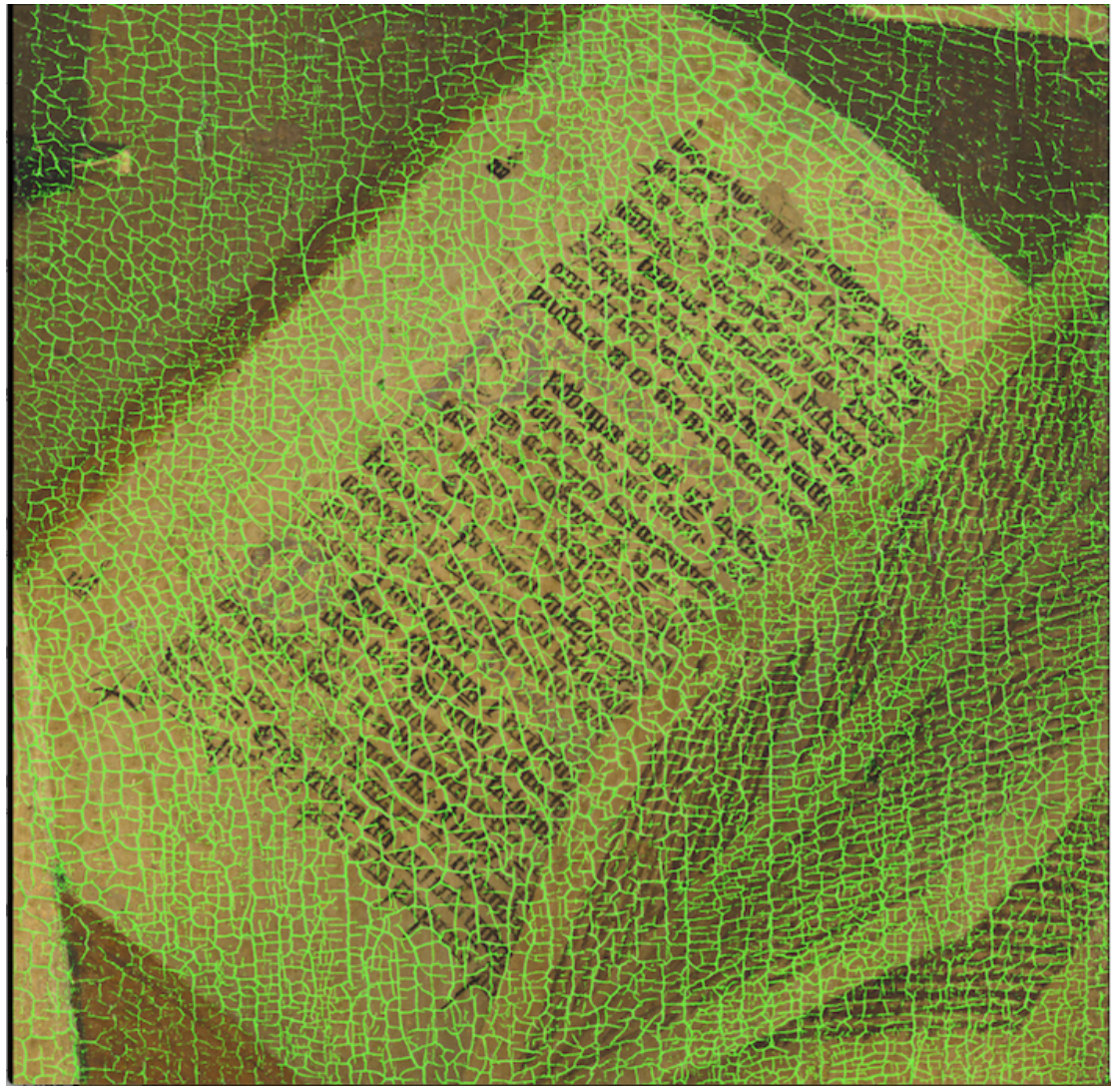
T. Ruzic and A. Pizurica. Context-Aware Patch-Based Image Inpainting Using Markov Random Field Modeling. *IEEE Transactions on Image Processing*, 2015.

Global Inpainting as puzzle solving



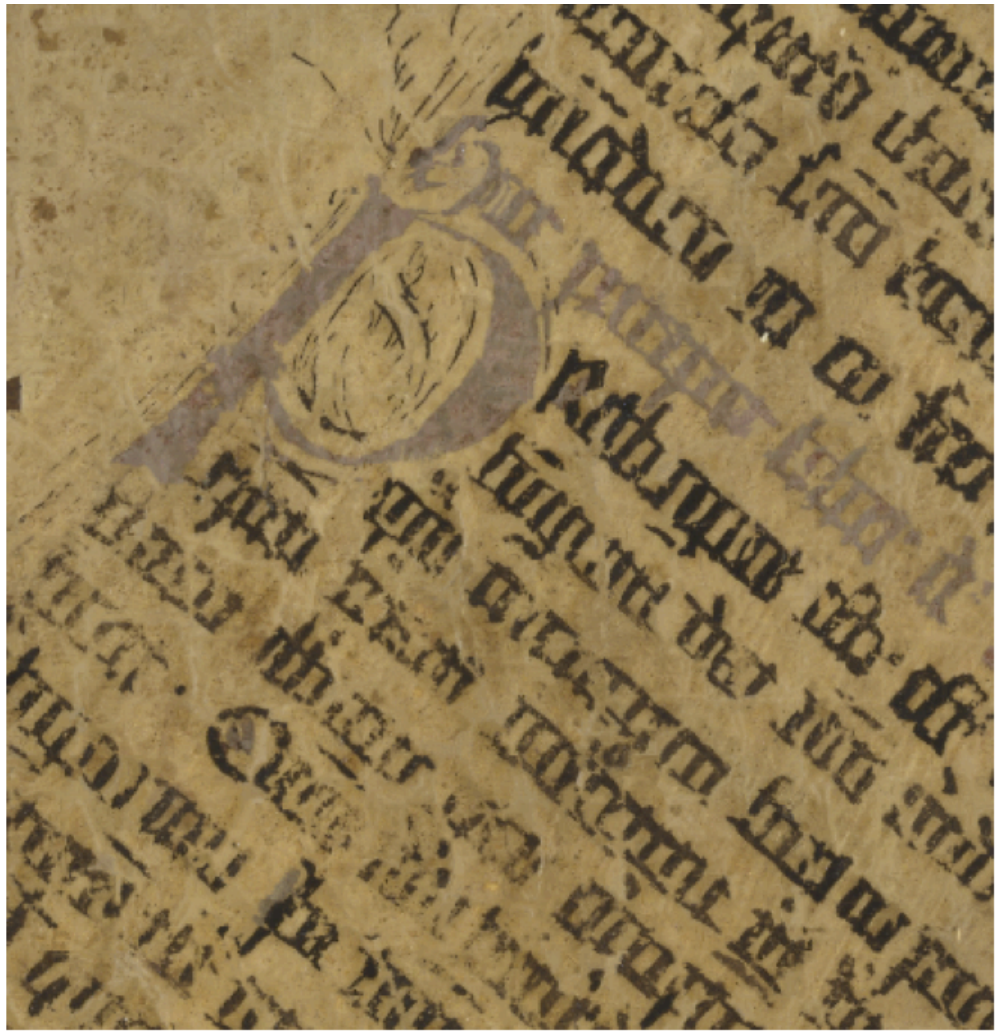
Virtual restoration

Crack detection

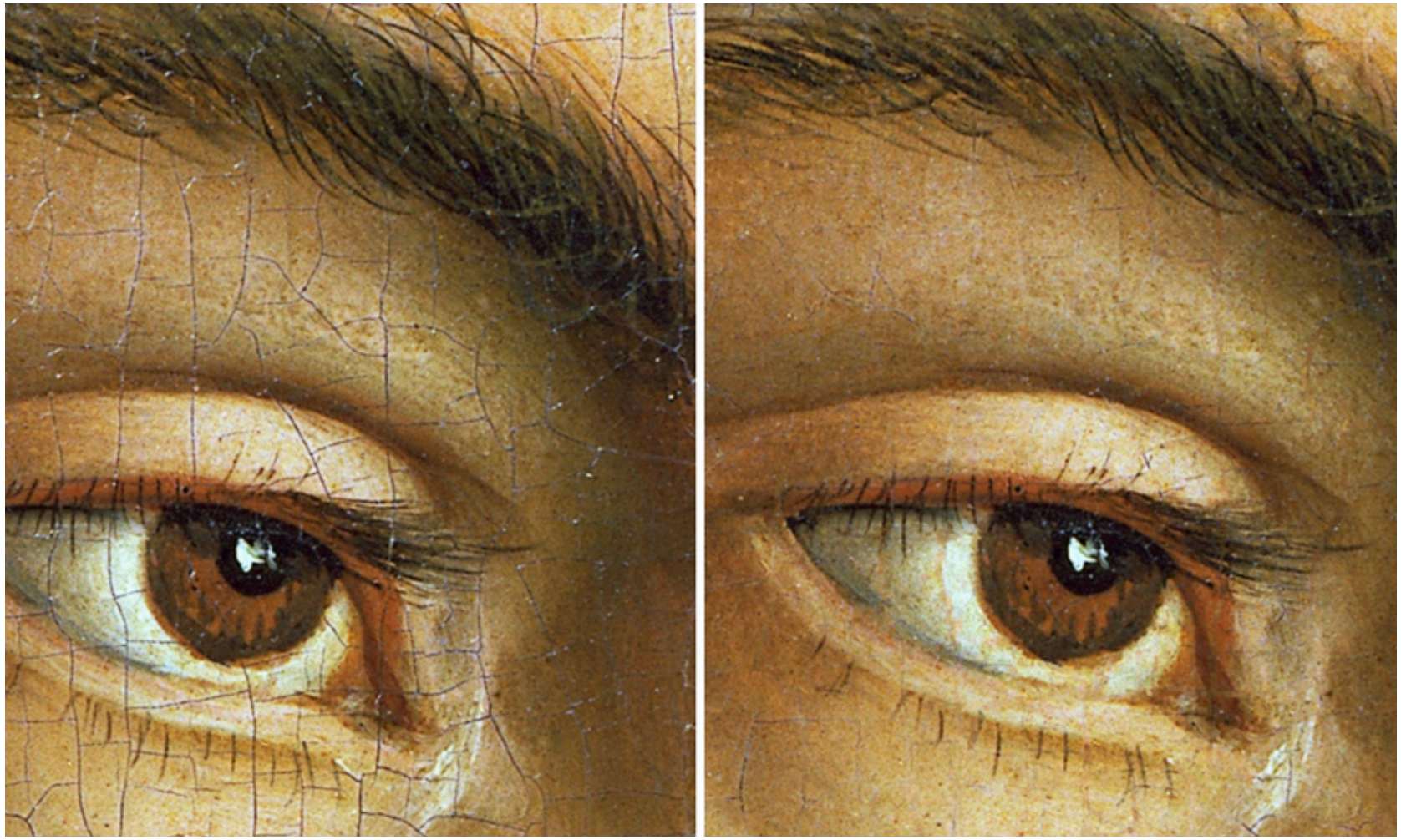


R. Sizyakin, B. Cornelis, L. Meeus, M. Martens, V. Voronin, and A. Pižurica. A deep learning approach to crack detection in panel paintings. IP4AI 2018.

Virtual restoration



Applications: inpainting (photo editing)



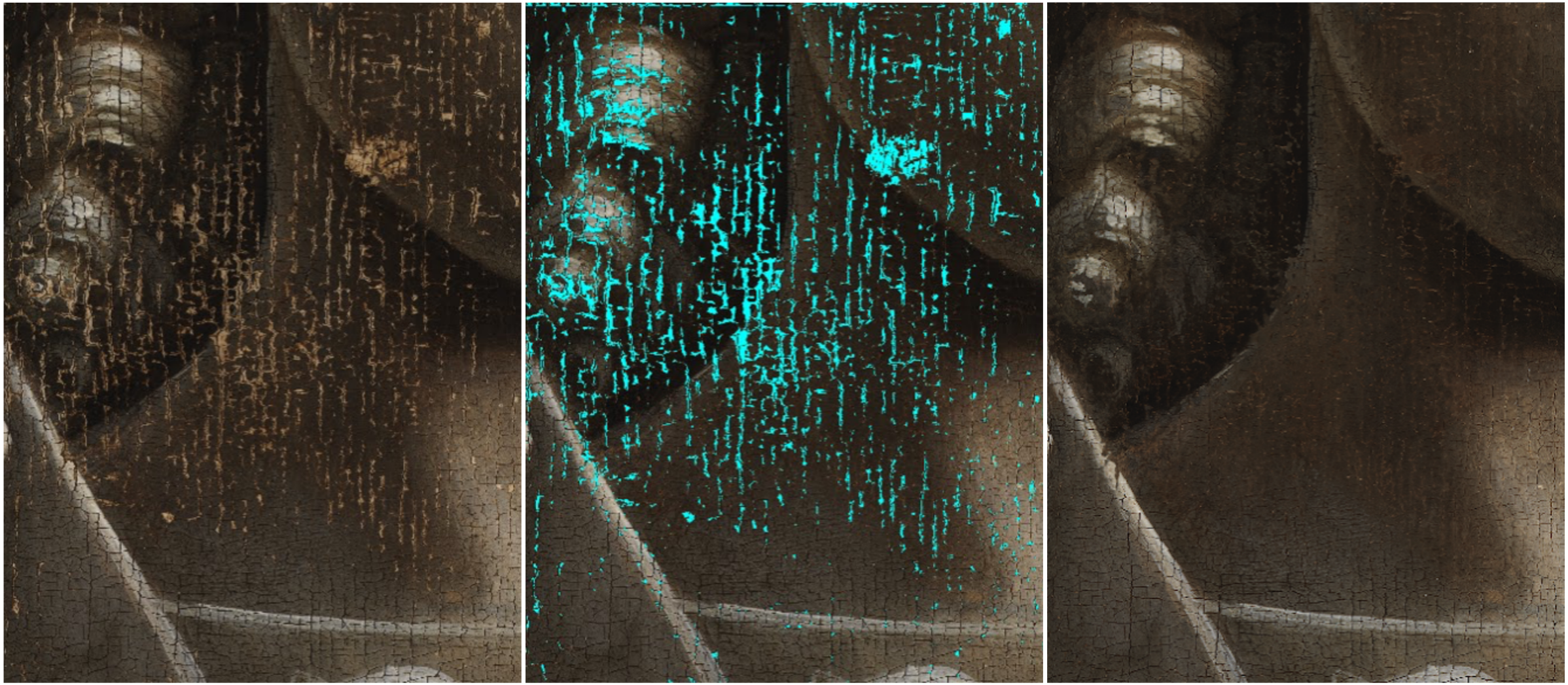
Inpainting: T. Ruzic and A. Pizurica. Context-Aware Patch-Based Image Inpainting Using Markov Random Field Modeling. *IEEE Trans. Image Process*, 2015.

Automatic paint loss detection and inpainting

(5954 x 7546) processed in < 1 minute

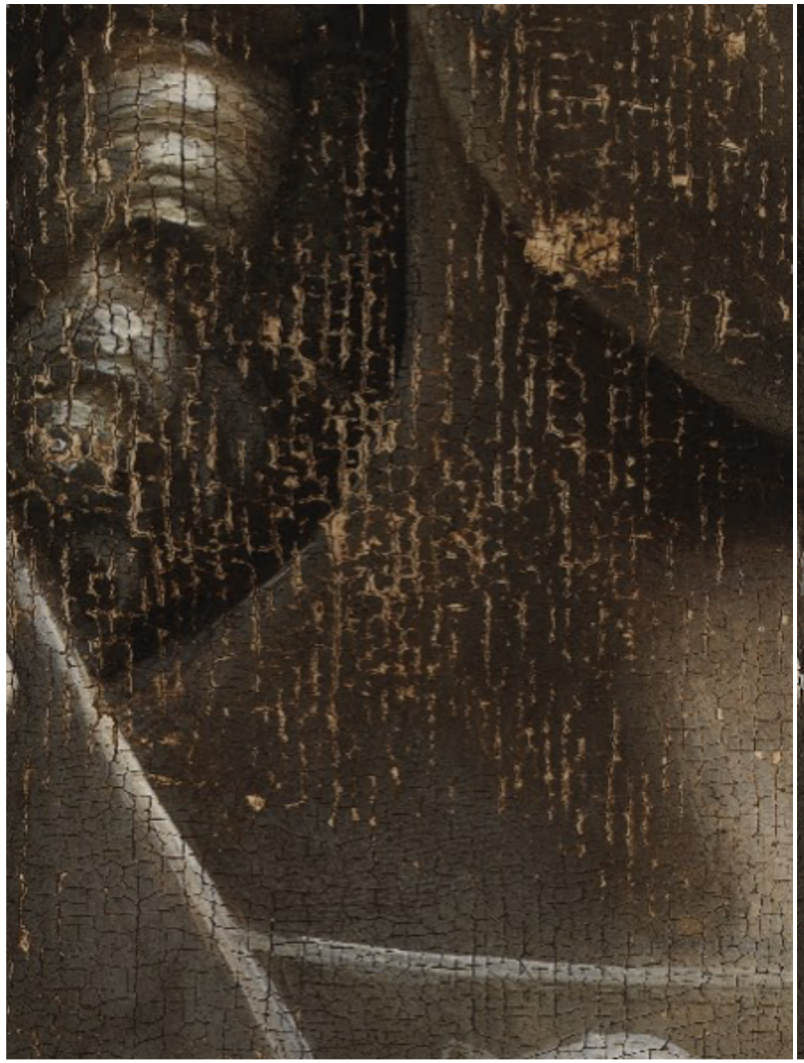
L. Meeus, S. Huang, B. Devolder, M. Martens, and A. Pizurica. **Deep Learning for Paint Loss Detection: A case Study on the Ghent Altarpiece.** IP4AI'2018.

Automatic paint loss detection and inpainting



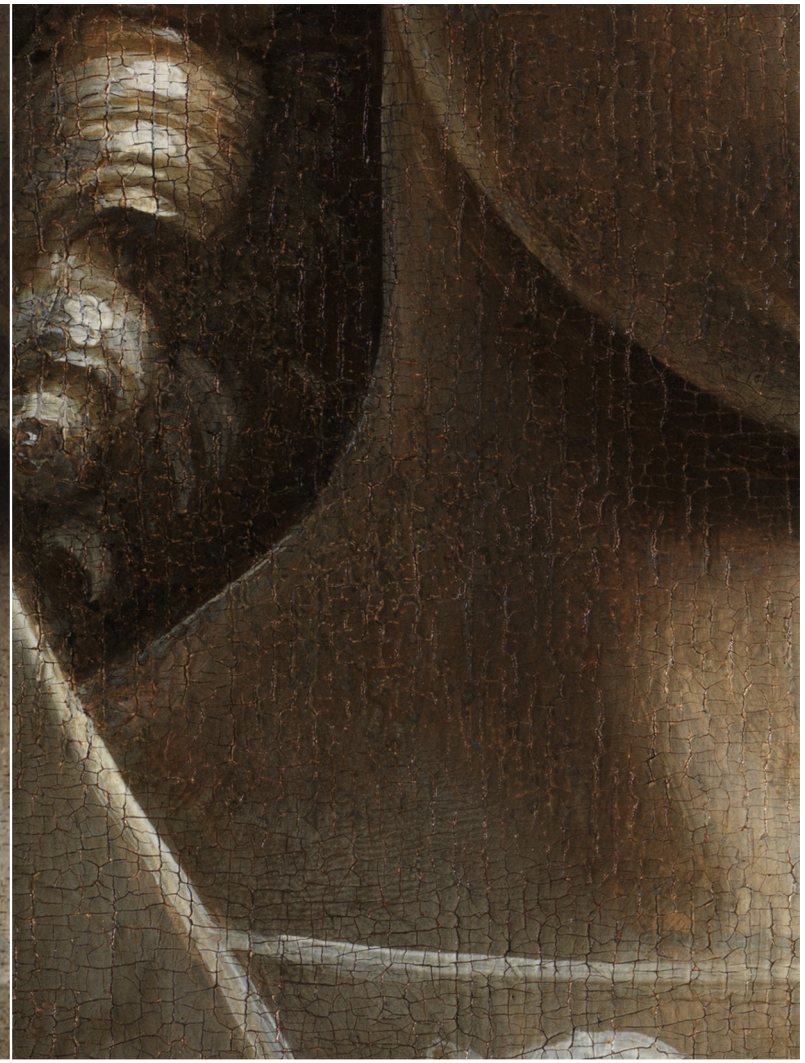
Inpainting: T. Ruzic and A. Pizurica. Context-Aware Patch-Based Image Inpainting Using Markov Random Field Modeling. *IEEE Trans. Image Process*, 2015.

Comparison with actual restoration



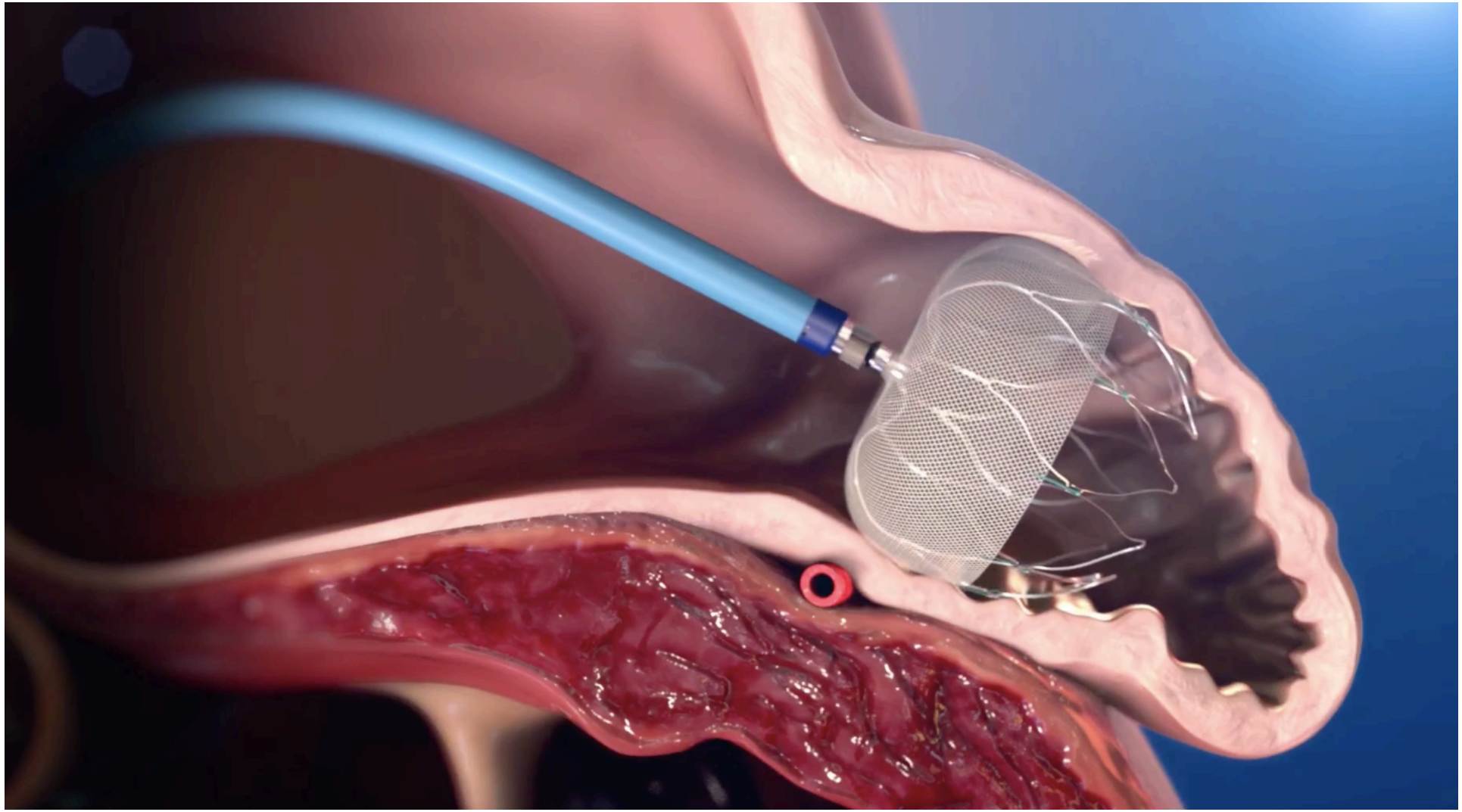
Damaged

Virtual inpainting

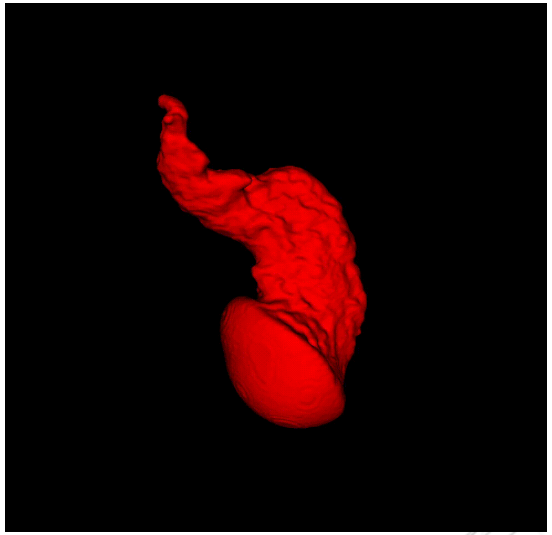


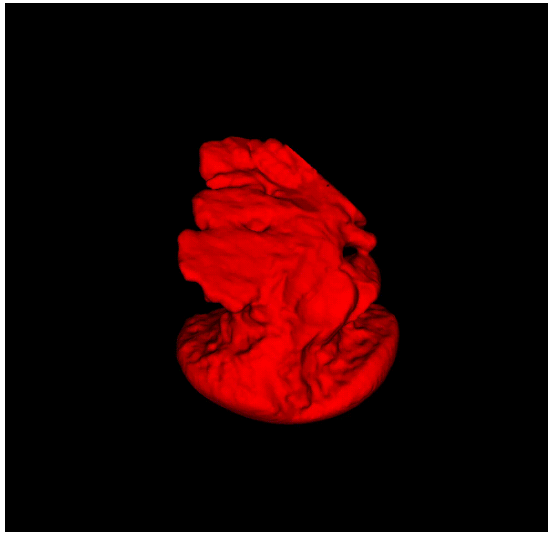
Actual restoration

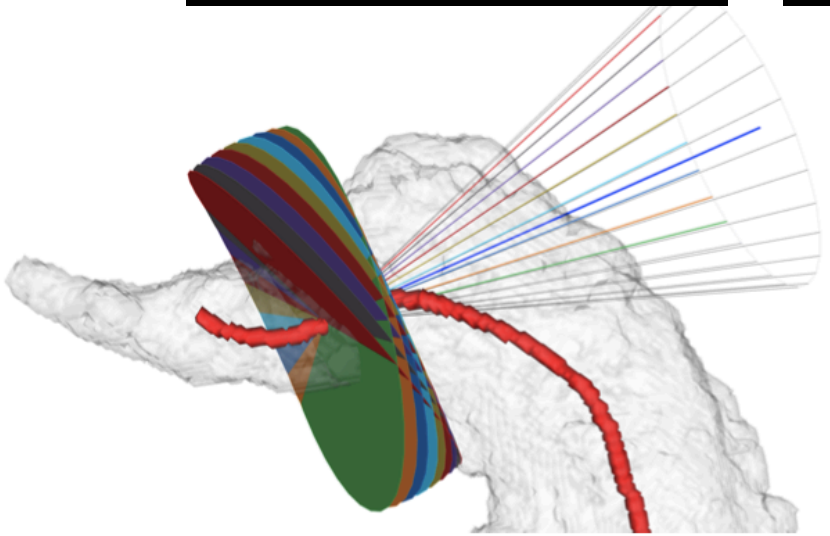
Support for surgical planning

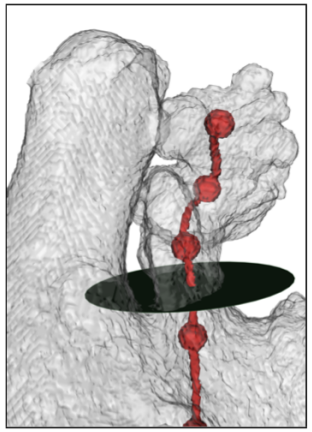


Support for surgical planning









PhD Hrvoje Leventic, 2019 (Promoters: I. Galic, A. Pizurica and D. Babin)

Geometric deep learning

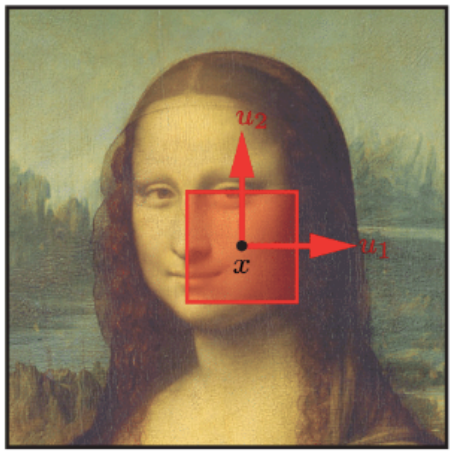
Deep learning research focused so far mainly on Euclidean data

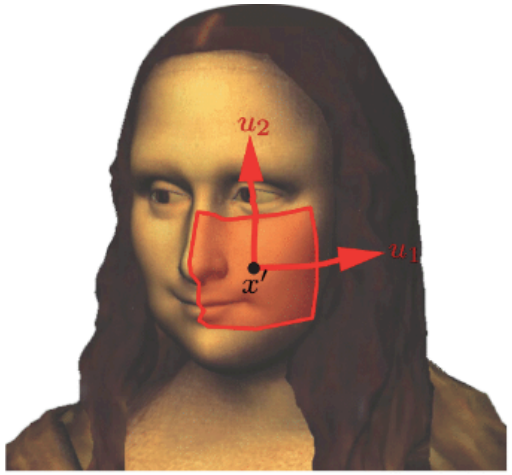
i.e., data on regular grids, such as images

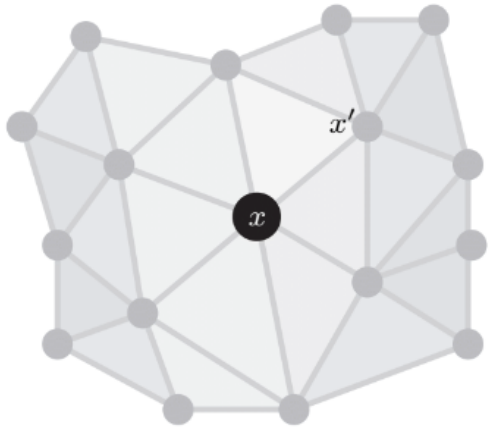
How to extend this to graphs and manifolds?

E.g., convolutional neural nets (CNN) involve convolutions;

How to define convolution on manifolds?





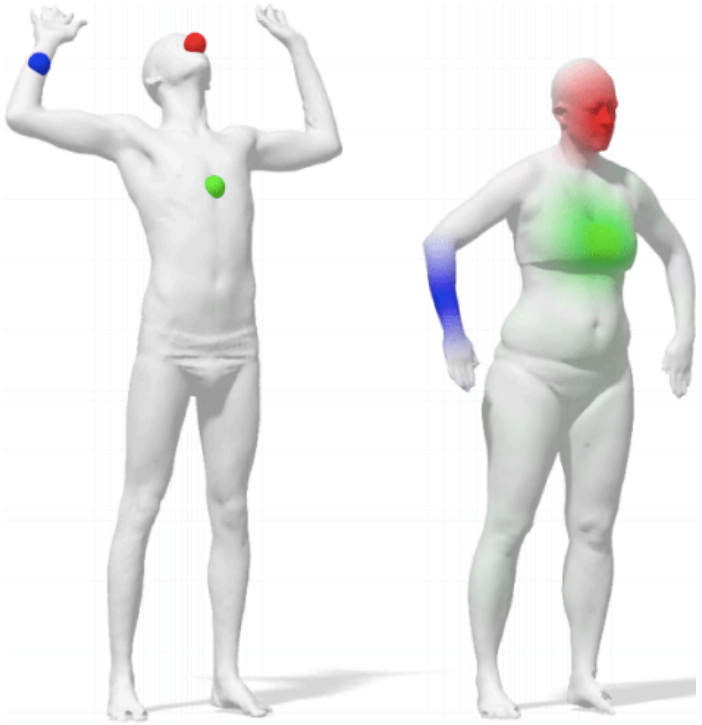


M. Bronstein et al. Geometric deep learning on graphs and manifolds. SIAM 2018.

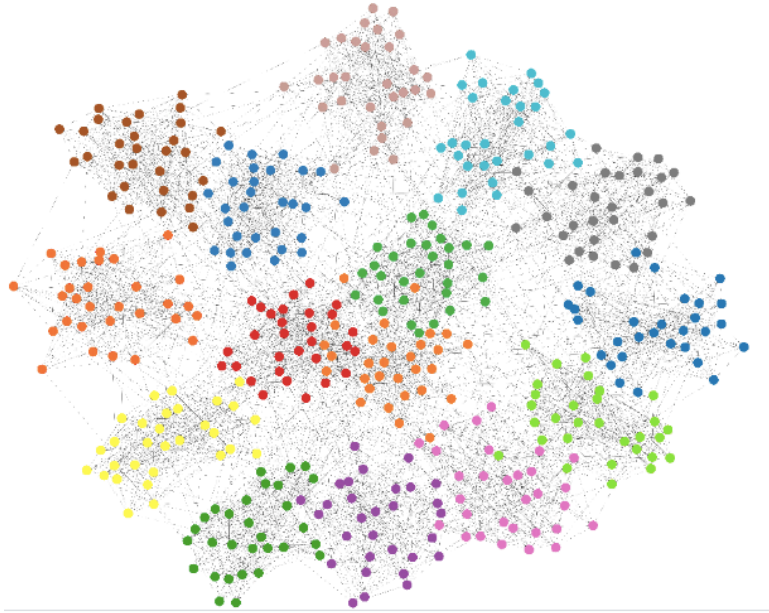
Geometric deep learning

Geometric deep learning extends the deep learning framework to graphs and manifolds

Classification of point cloud data

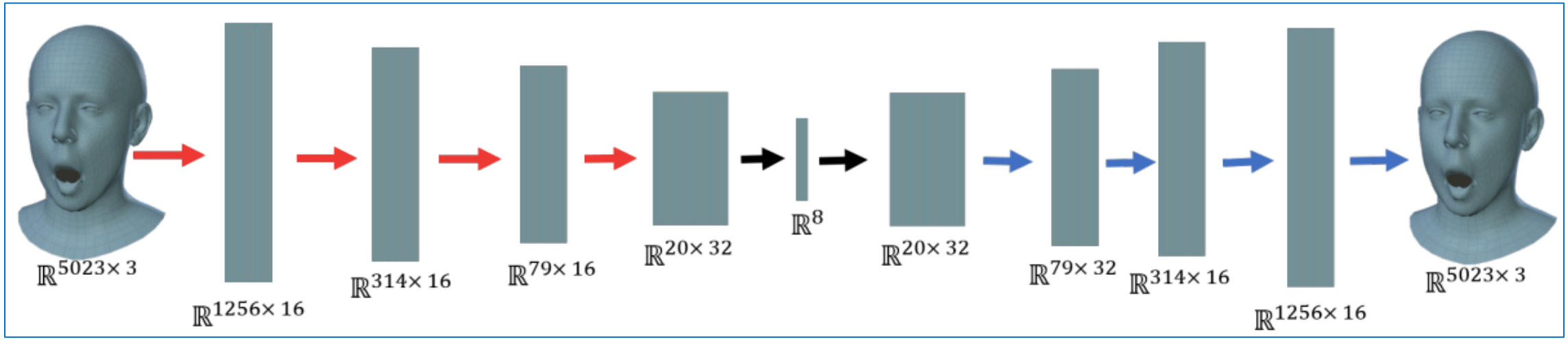


Correspondence learning on manifolds

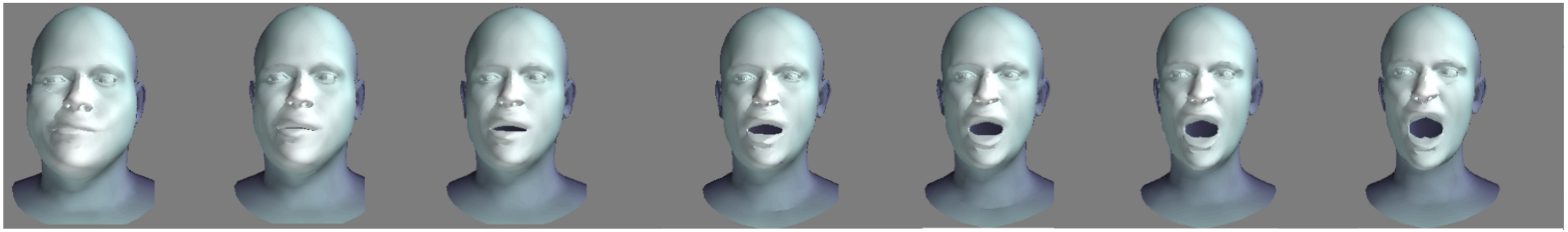


Learning on graphs (like social nets)

Geometric deep learning



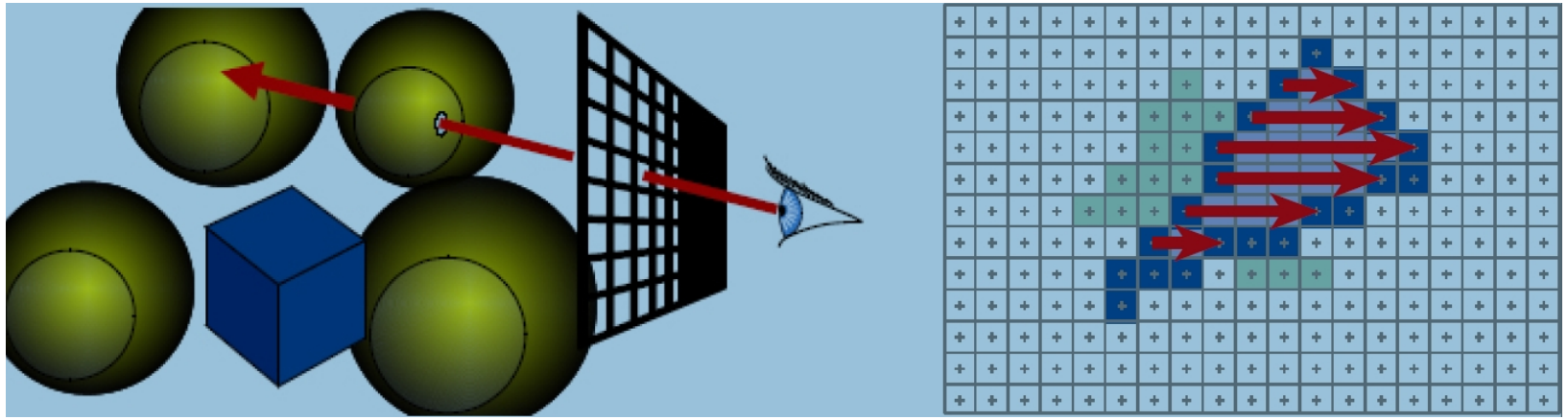
A. Ranjan et al. Generating 3D faces using Convolutional Mesh Autoencoders, 2018.



N. Vercheval, H. De Bie and A. Pižurica. Variational autoencoders without graph coarsening for fine mesh learning, 2020.

Graphics pipeline

The rendering pipeline



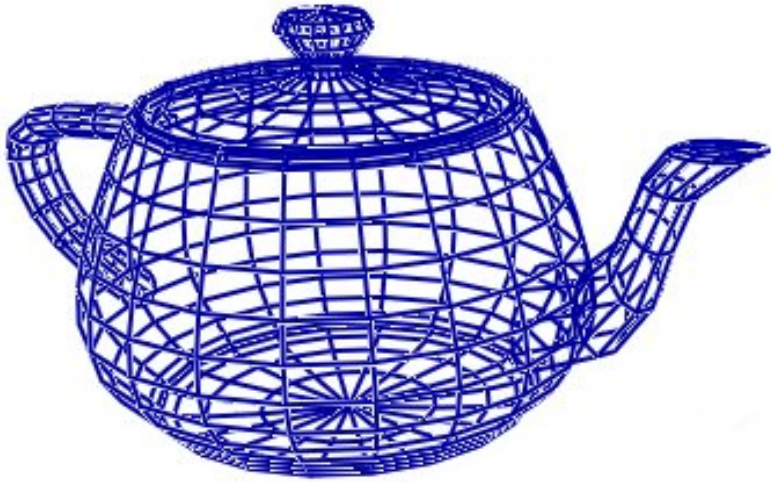
MIT open courseware

Different steps in the graphics rendering pipeline:

- Vertex processing (convert vertices to 2D screen positions)
- Clipping – removing the invisible parts
- Rasterization
- Occlusion culing – removing pixels hidden by other objects
- Shading – adding texture and final color
- Frame buffer controler - interface to the physical memory

Interesting to know…

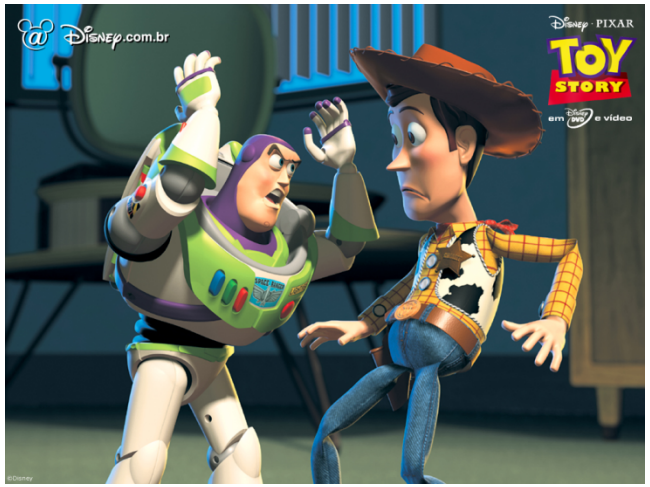
Computer graphics models



One of the most popular computer graphics models is “teapot”

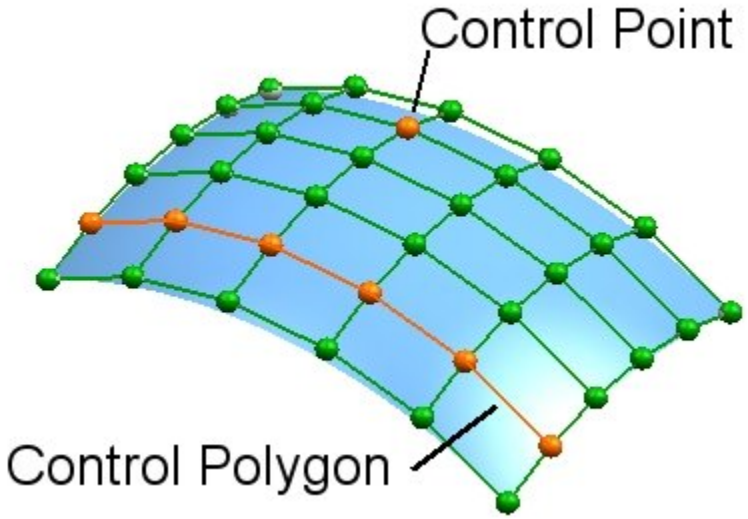
The photo shows the actual “Melitta” teapot that Martin Nevell digitized in 1975. (Now in the *Computer History Museum* in Silicon Valley)

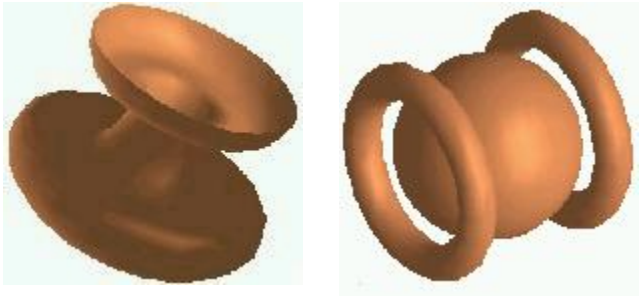
NURBS – Non Uniform Rational B Splines



Toy Story
Disney Pixar

- Commonly used in computer graphics for generating and representing curves and surfaces
- Great flexibility and precision for handling both analytic and freeform shapes





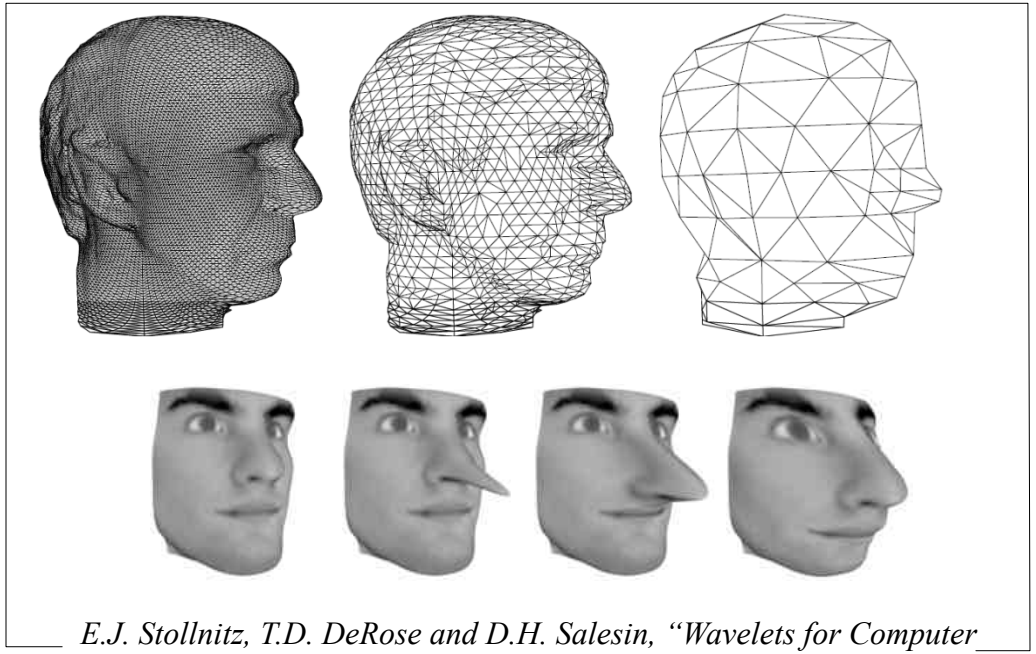
A modeling example
ARIA - Mark Spink Production

Subdivision surfaces

Geri's game

Disney Pixar

https://www.youtube.com/watch?v=9IYRC7g2ICg



E.J. Stollnitz, T.D. DeRose and D.H. Salesin, "Wavelets for Computer Graphics: A Primer Part 2, IEEE Comp. Graph. and Appl., July 1995.

- Polygon mesh representation
- A "smooth" surface calculated from the coarse mesh by recursively subdividing each polygonal face into smaller faces
- More flexible than NURBS