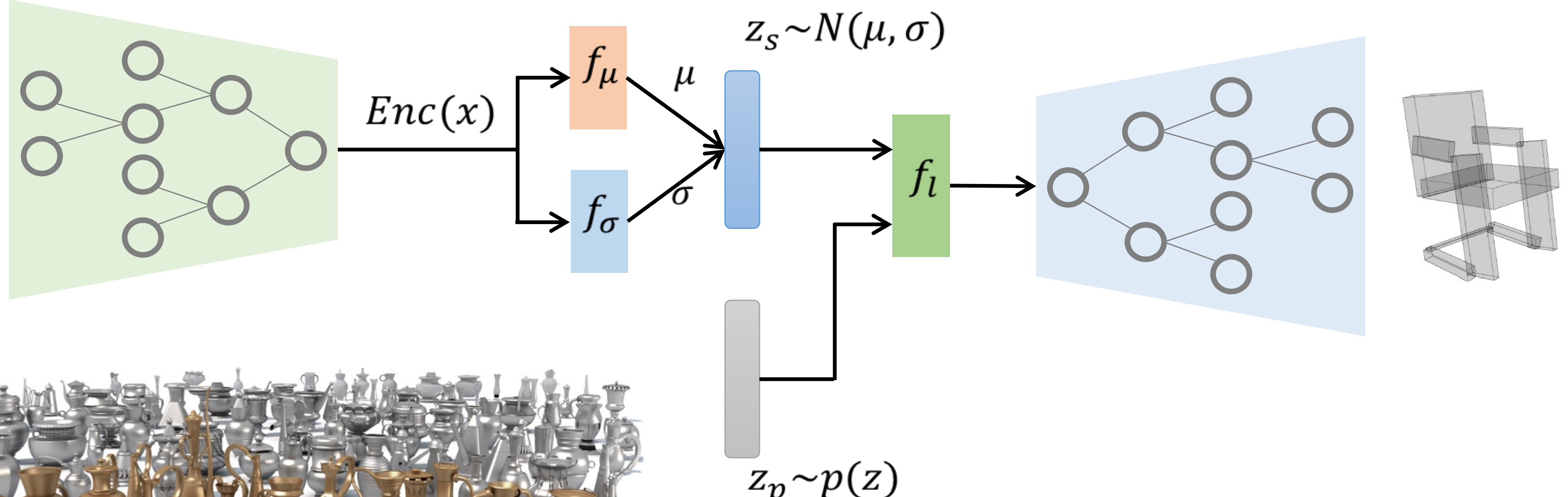
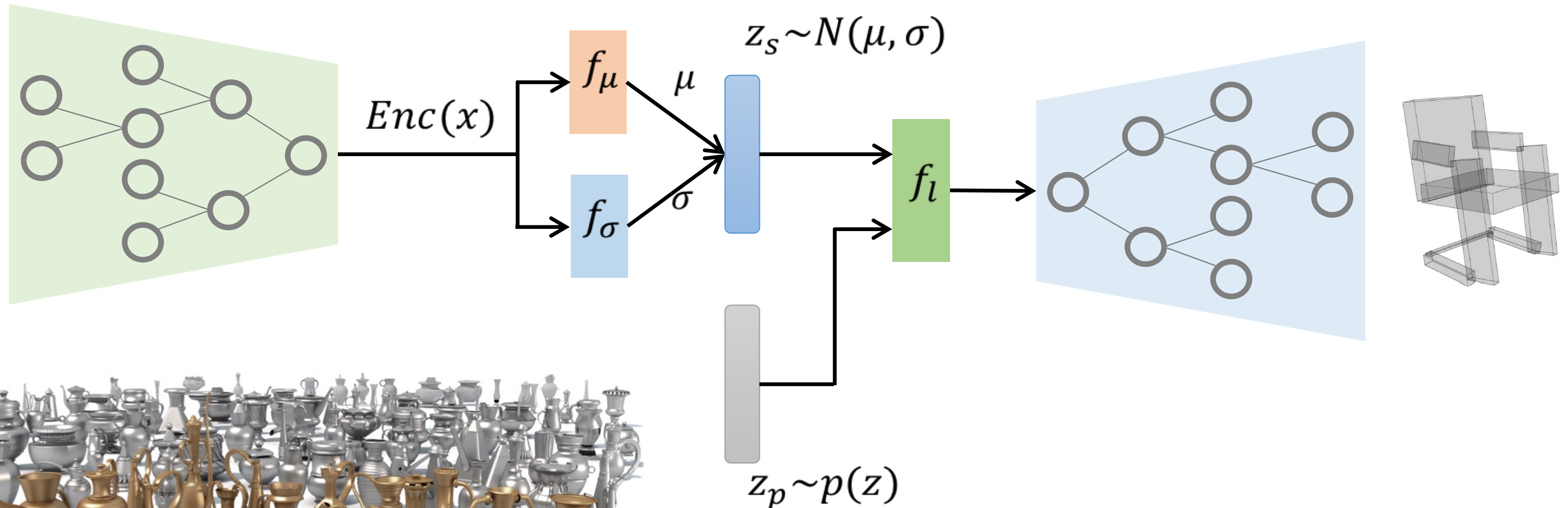
Computer Graphics and Geometric Modeling in the AI Era

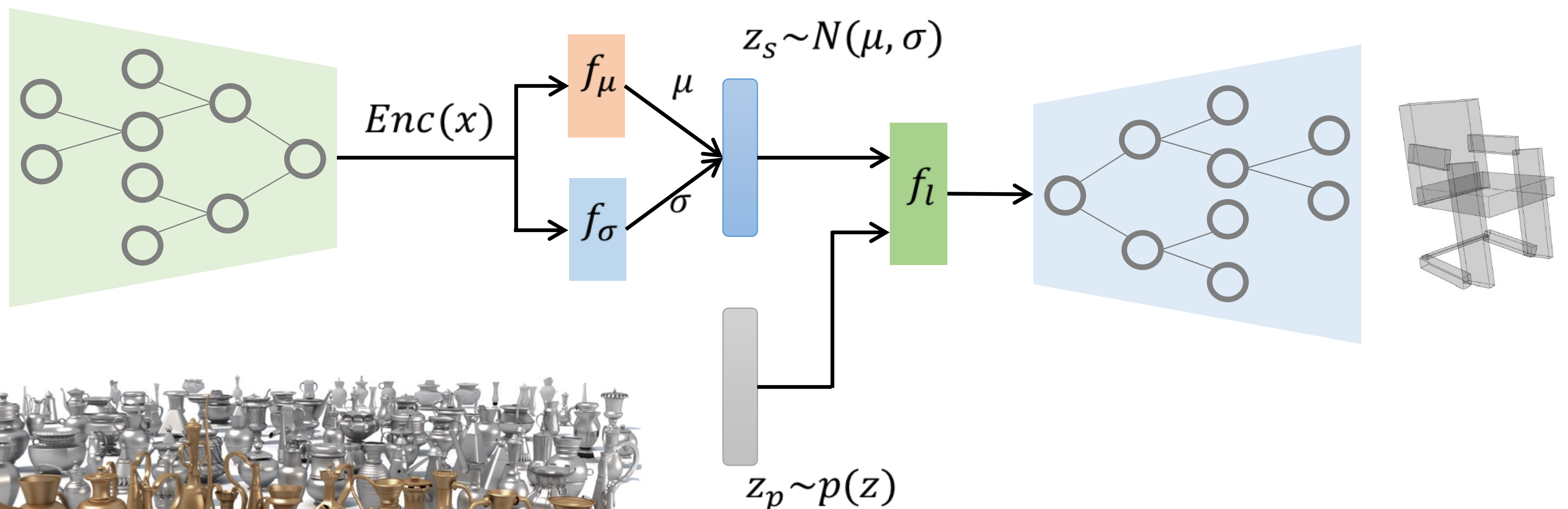


CMPT 464/764 Lecture 0

Why is geometric modeling such an important topic in graphics?

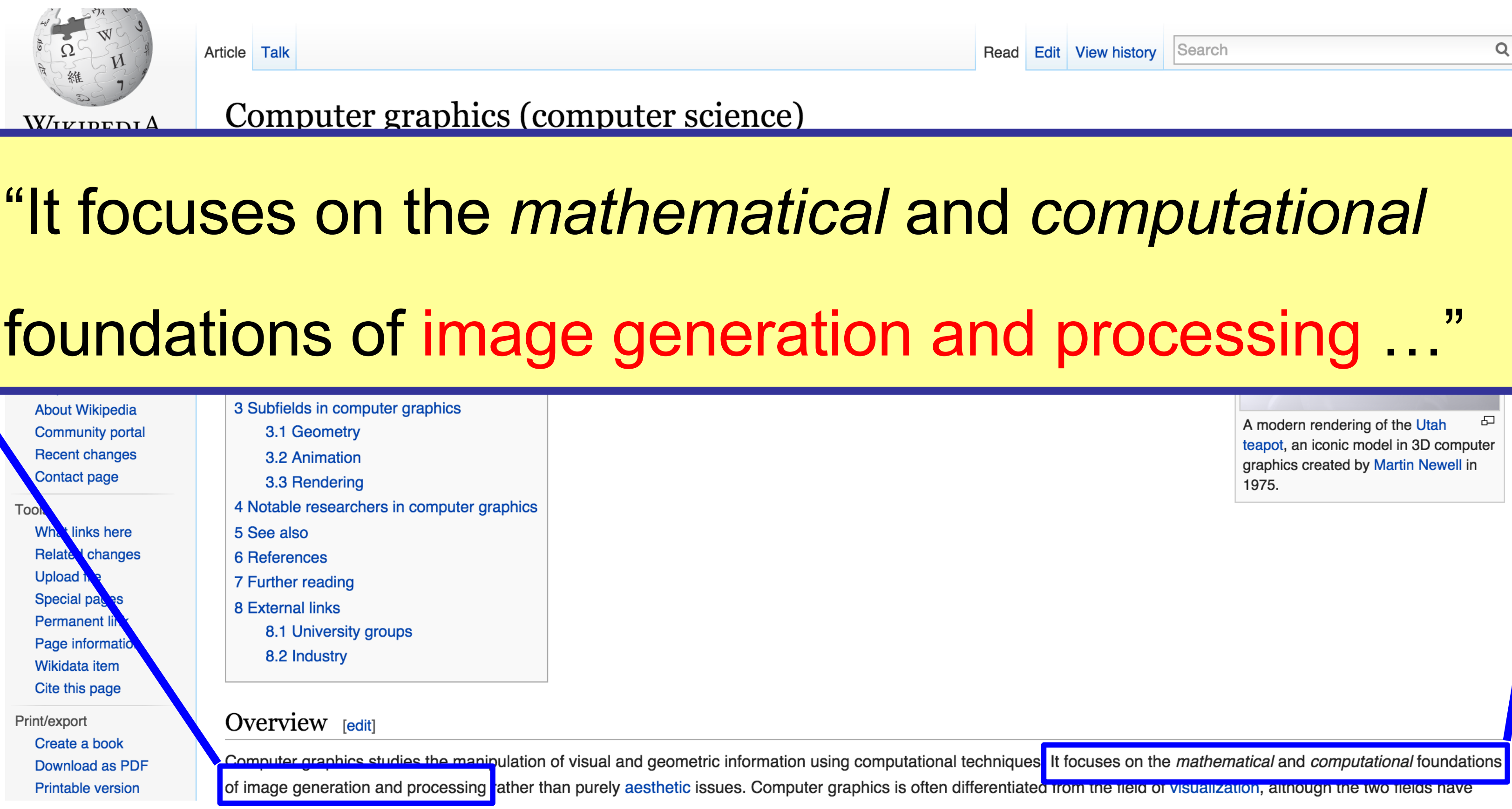


What is computer graphics – then and now – the BIG picture



What is computer graphics?

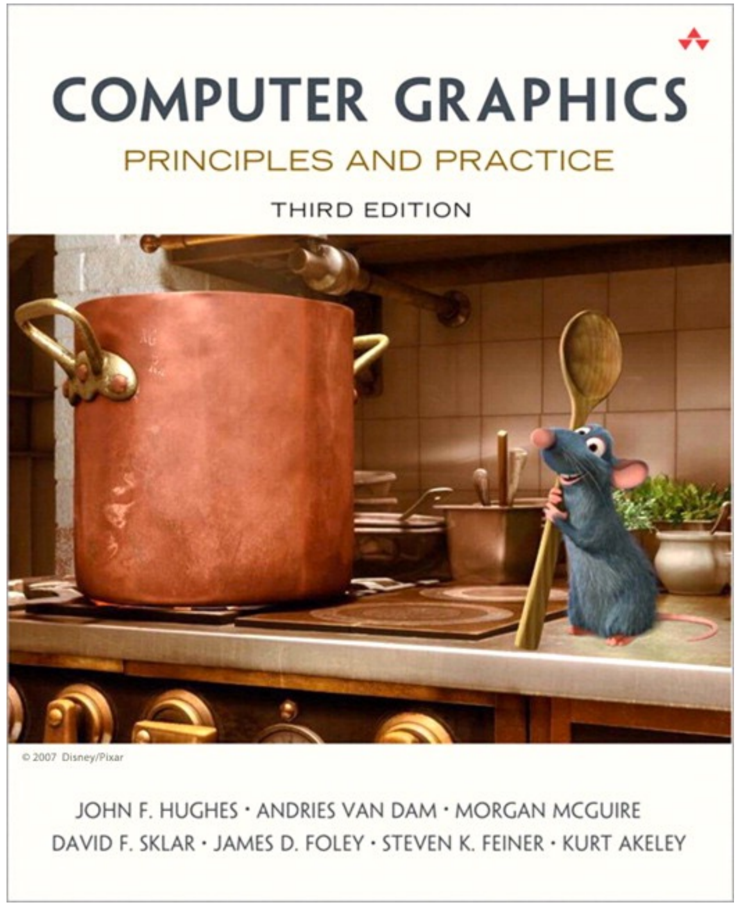
- Wikipedia: computer graphics (computer science)



"It focuses on the *mathematical* and *computational* foundations of image generation and processing …"

What do the experts say?

Perhaps the most classic computer graphics textbook

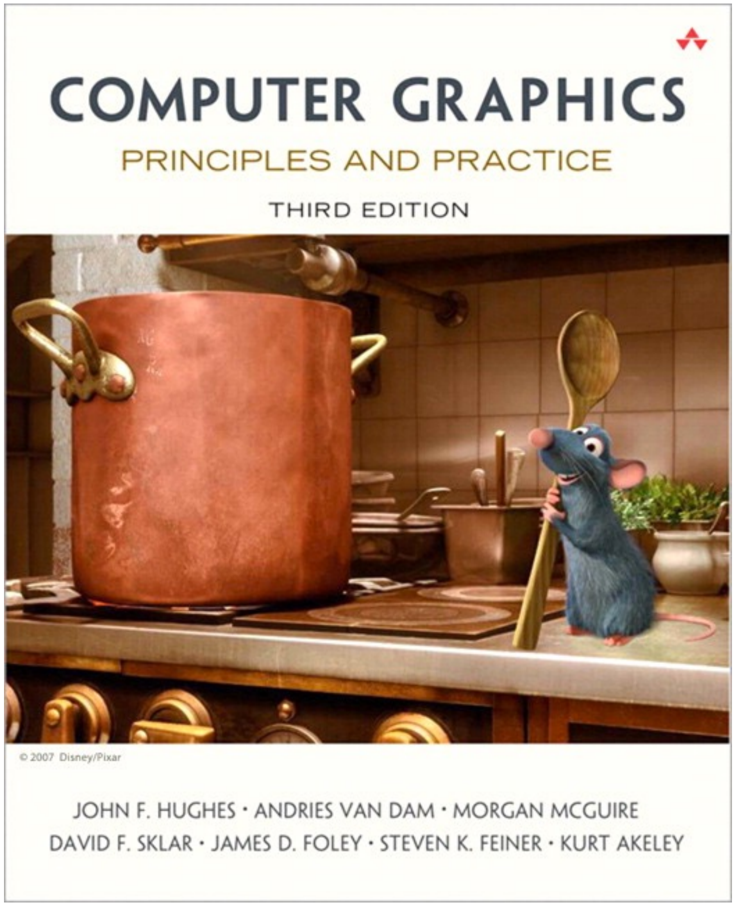


Third edition @ 2014

What do the experts say?

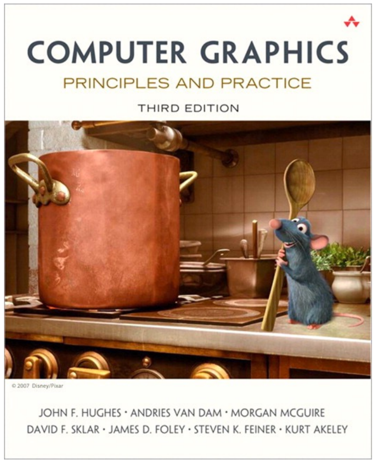
- Hughes, van Dam, et al.:
  - "Computer graphics is the science and art of communicating visually via a computer's display and its interaction devices."

------ *page 1.*



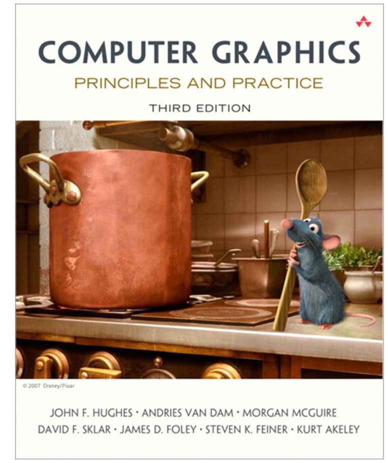
Third edition @ 2014

Classical computer graphics



- Hughes, van Dam, et al.:
  - "Taking a model of the objects in a scene and a model of the light emitted into the scene and producing a representation of a particular view of the scene."

Classical computer graphics



- Hughes, van Dam, et al.:
  - "Taking a model of the objects in a scene and a model of the light emitted into the scene and producing a representation of a particular view of the scene."
  - "A glorified multiplication: multiplying incoming light by reflectivity of objects … for all light reaching the camera"

------ *page 2, "A narrow definition".*

List of topics from CMPT 361

- The graphics (vertex & pixel) pipeline
- Transformation, viewing, projection, clipping & visibility
- Light, color, local & global illumination
- Sampling and reconstruction: Fourier transform; aliasing
- Image representation, manipulation, and texture mapping
- Curves, surfaces, meshes, and other geometry reps

All about model representation and rendering

Classical computer graphics

- Explicit scene description is given
- Key problem #1: how to best represent geometry, texture, and lighting for the given scene

Classical computer graphics

- Explicit scene description is given
- Key problem #1: how to best represent geometry, texture, and lighting for the given scene
- Key problem #2: how to render the scene with
  - Efficiency

A forward problem:

Explicit model description ➡ rendered image

The "forward" problem

- "The quick brown fox jumps over a lazy dog."
- Need explicit models for
  - A brown fox
  - A dog
  - Quick jump
  - Sleeping dog …

The "forward" problem

- "The quick brown fox jumps over a lazy dog."
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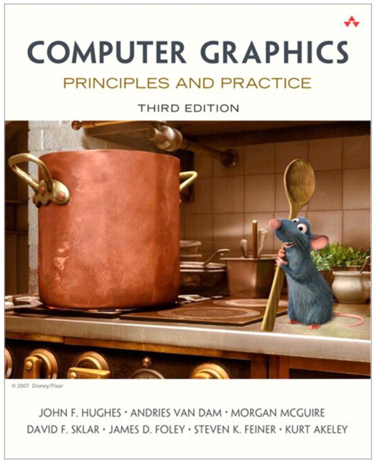
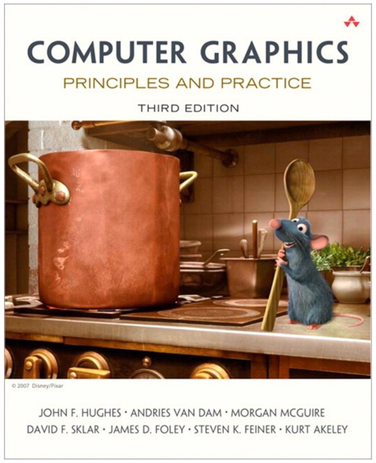
What about computer vision?



- Lower level:
  - Analysis: given one view of a scene, determine the illumination and the scene's content, which a graphics system could use to produce the scene

What about computer vision?



- Lower level:
  - Analysis: given one view of a scene, determine the illumination and the scene's content, which a graphics system could use to produce the scene
- Higher level: infer an understanding of what are

An inverse problem:
From a rendered image to a model description

The “inverse” problem

- Ask Claude: Please describe this image.

The "inverse" problem

- Ask Claude: Please describe this image.
  - There is a fox
  - There is a dog
  - Fox jumps over dog
  - Fox is quick
  - Dog is lazy …

Graphics vs. vision

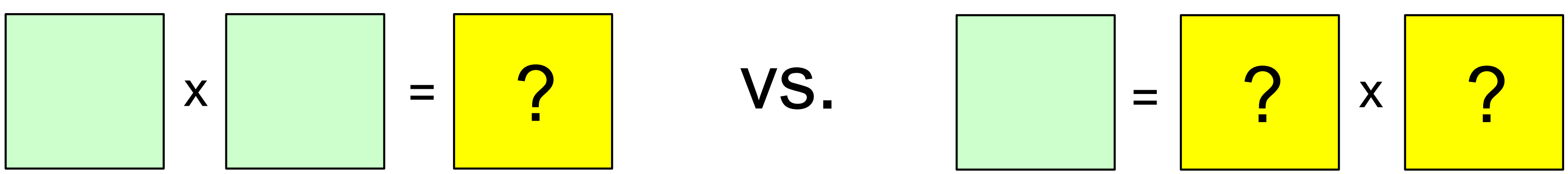
- Graphics is about synthesis
  - Classical graphics is about image synthesis

Graphics vs. vision

- Graphics is about synthesis
    - Classical graphics is about image synthesis
- Vision is about image analysis

Graphics vs. vision – classically

- Graphics is about synthesis
  - Classical graphics is about image synthesis
- Vision is about image analysis
- In classical setting, they were opposite problems
  - Forward vs. inverse problems: which is harder? ☺



Graphics vs. vision – diff in DATA

- Before jumping to "the new graphics", what would be the one big difference between "data in graphics" and "data in computer vision"?

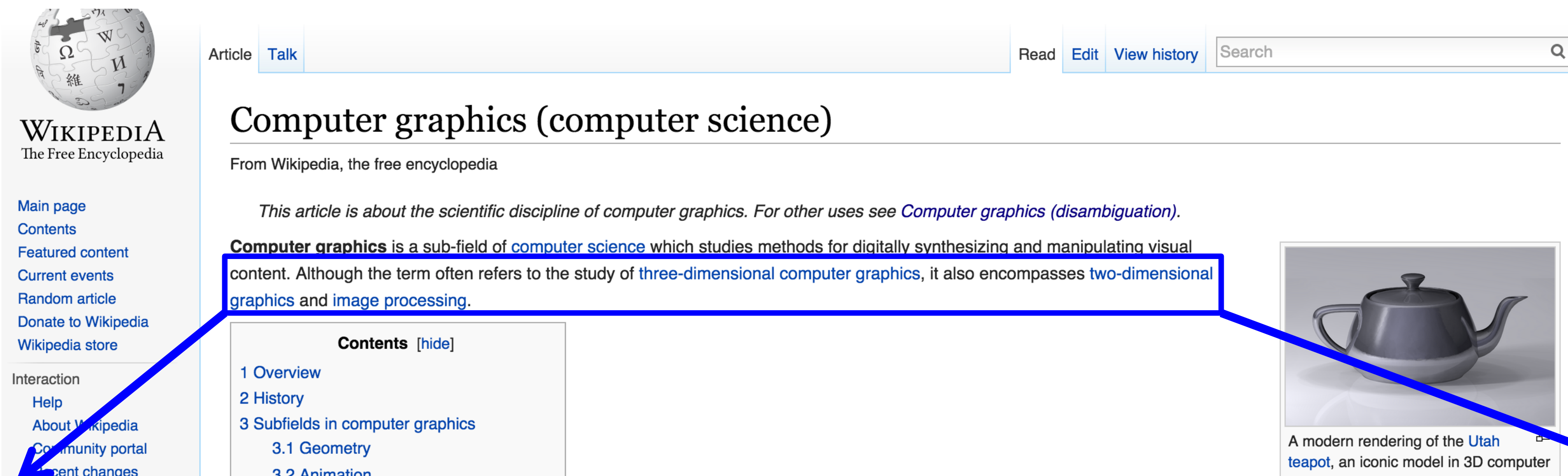
2D image data for computer vision

vs.

3D shape/scene data for computer graphics

Graphics vs. vision – diff in DATA

- Wikipedia: computer graphics (computer science)



"Although the term (computer graphics) often refers to the study of three-dimensional computer graphics, it also encompasses two-dimensional graphics and image processing …"

The 3D data challenges

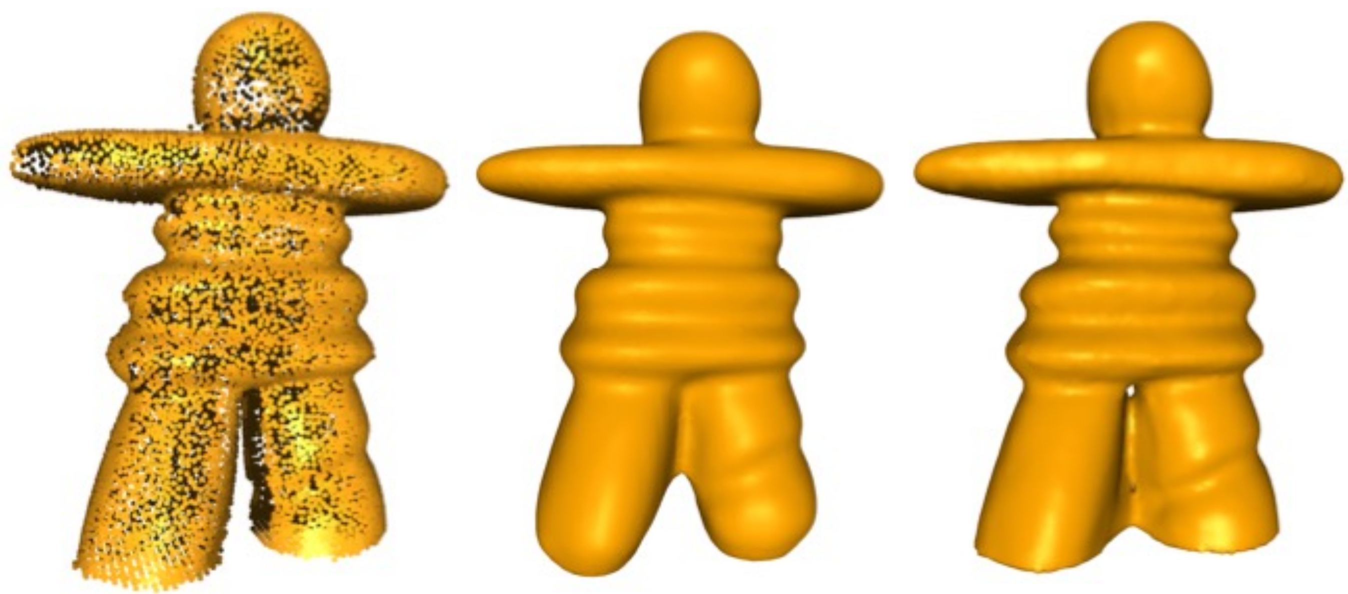
- Acquisition of 3D models is hard
- 3D modeling is hard
- Spatial reasoning and computation in 3D is hard
- Interaction in 3D is hard

3D challenge: acquisition

- Much harder to get 3D chairs than chair images

3D challenge: acquisition

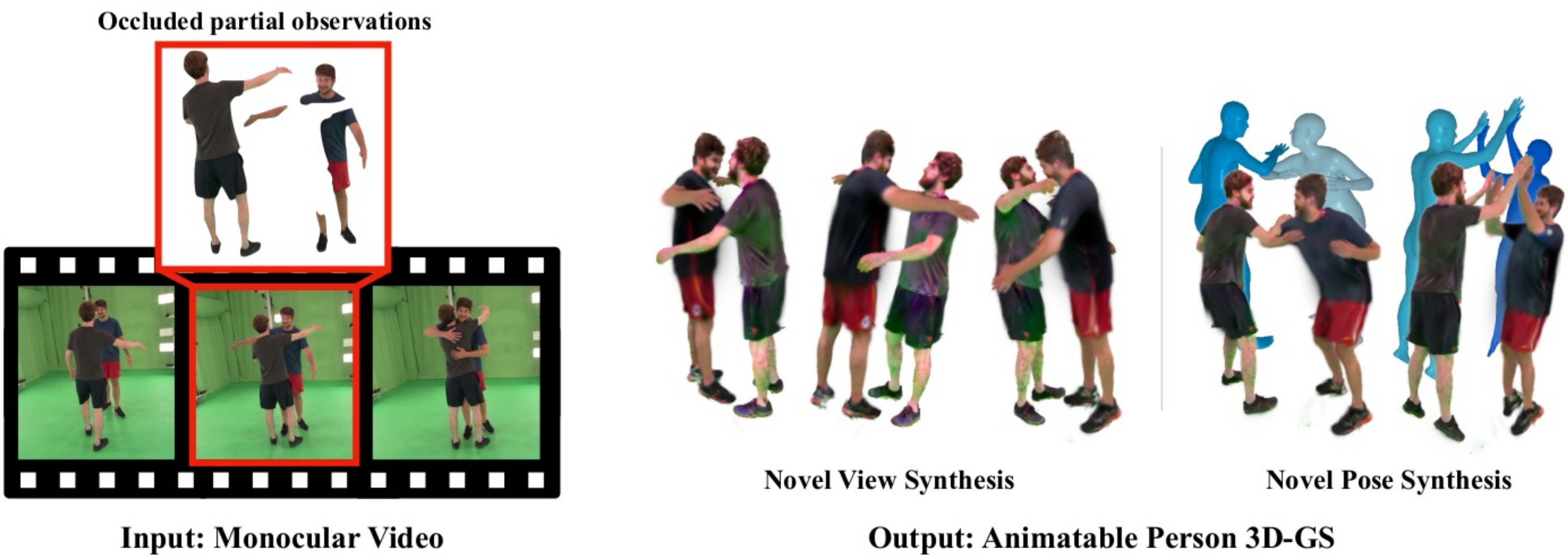
- Reconstruction or modeling from 3D or 2D inputs
- Missing data



Laser scan Poisson MPU

3D challenge: acquisition

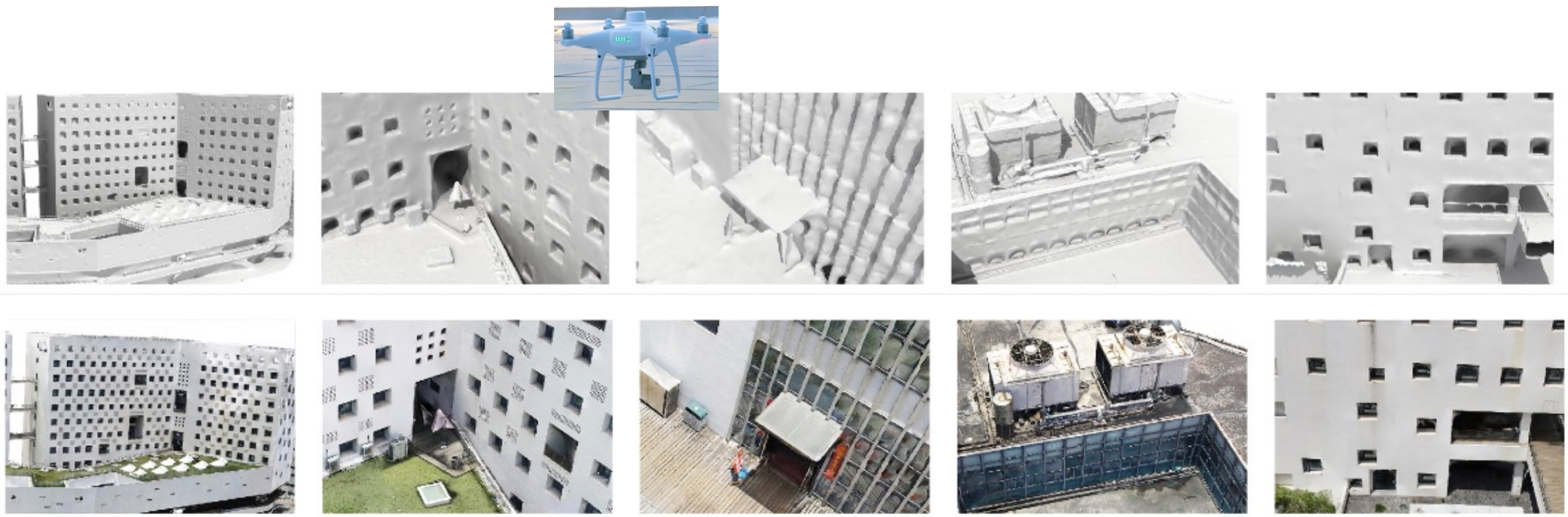
- Reconstruction or modeling from 3D or 2D inputs
- Missing data + dynamic data



[Lee et al. *CVPR* 2024]

3D challenge: acquisition

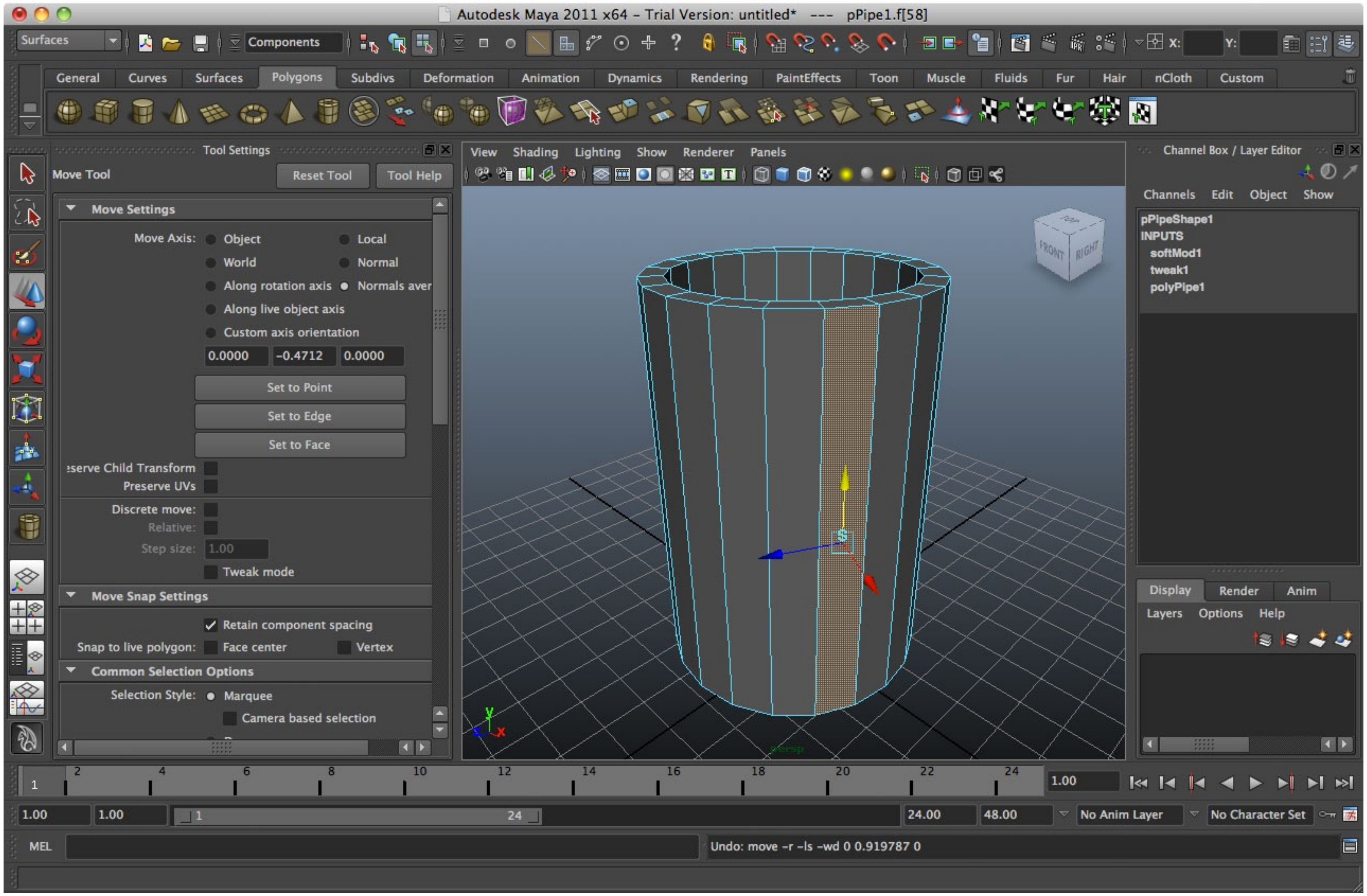
- Reconstruction or modeling from 3D or 2D inputs
- Missing data + dynamic data + large scales



[Liu et al. *SIGGRAPH Asia* 2022]

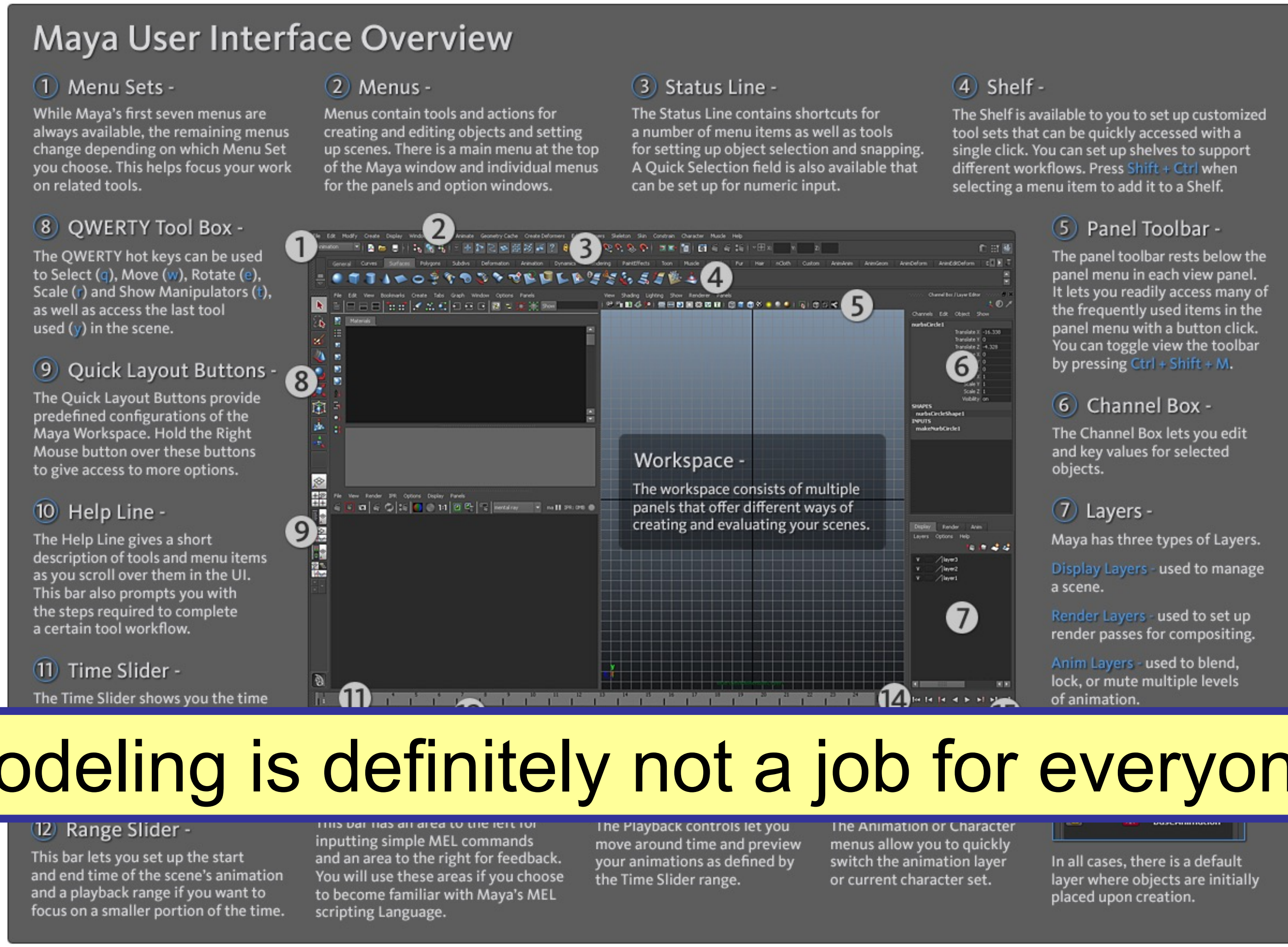
3D challenge: modeling

Autodesk
Maya



3D challenge: modeling

Autodesk Maya

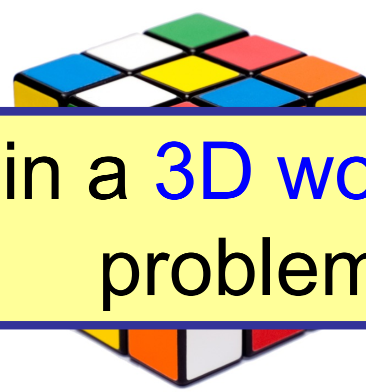
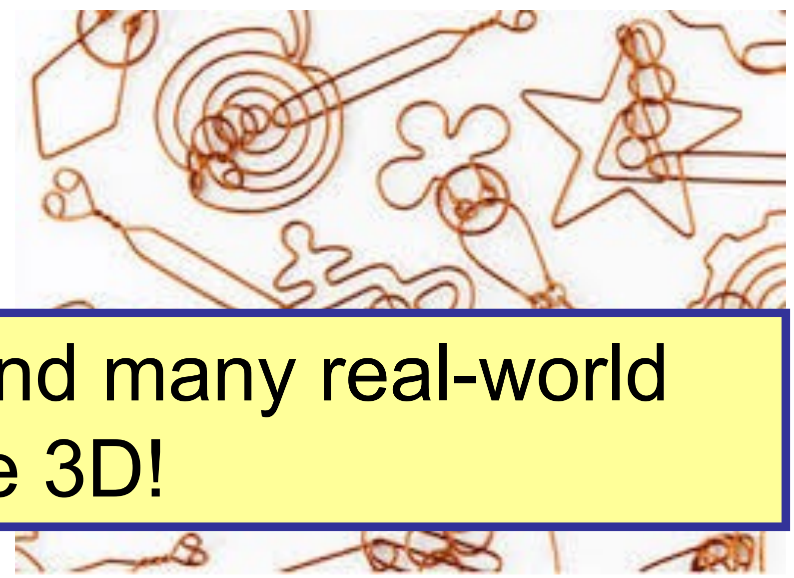


3D modeling is definitely not a job for everyone!

3D reasoning is hard

- Humans very good at pattern recognition (vision)
- But not so good at 3D reasoning or manipulation



But we live in a 3D world and many real-world problems are 3D!

Many real-world problems are 3D

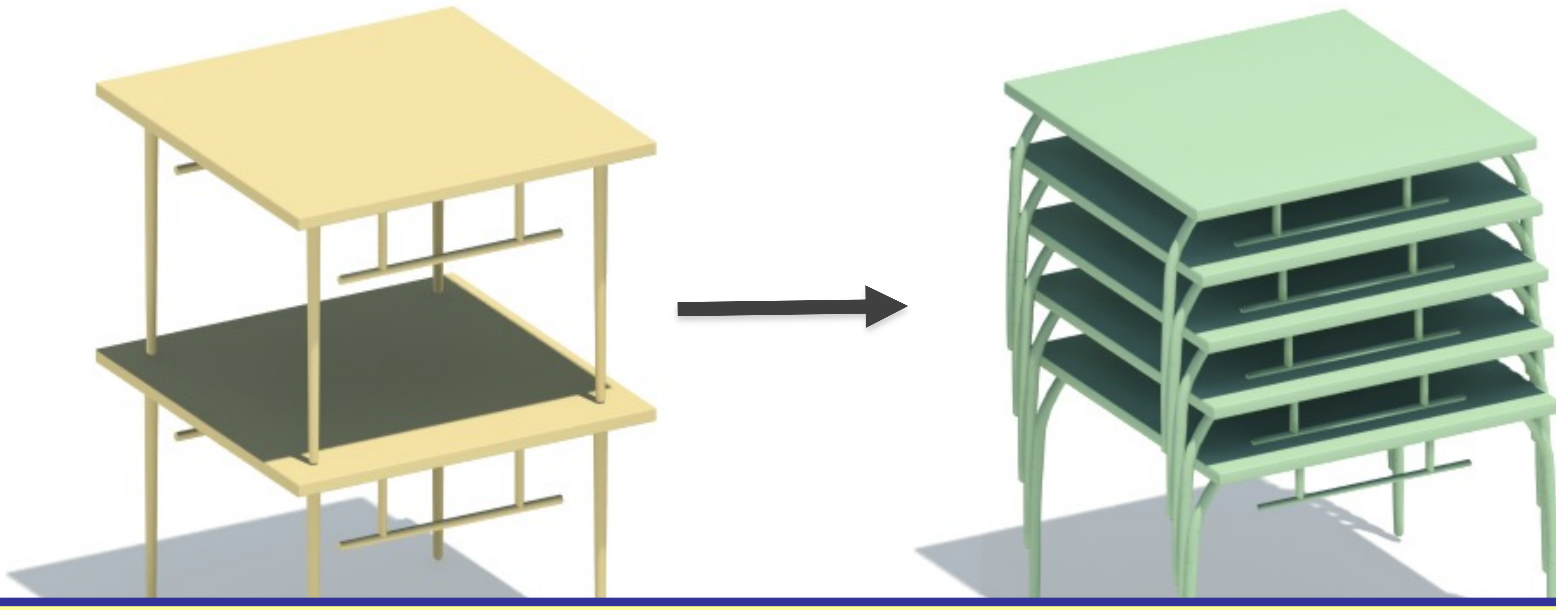
How to easily generate many 3D indoor scenes that are realistic and diverse, e.g., for AR/VR?

Many real-world problems are 3D

- How to subtly make the table stackable?

Stackabilization

- How to subtly make the table stackable?



Requires precise measurement and transform of 3D objects: difficult for human users to model

Foldabilization

- How to subtly make the chair foldable?

Like solving a puzzle:
acute 3D spatial reasoning
skills are needed

Computationally hard with
very large search space

[Li et al. *Siggraph* 2015]

Foldabilization

EMBRY-RIDDLE Aeronautical University
SCHOLARLY COMMONS

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Folding Methodology for Flexible Aircraft Interiors

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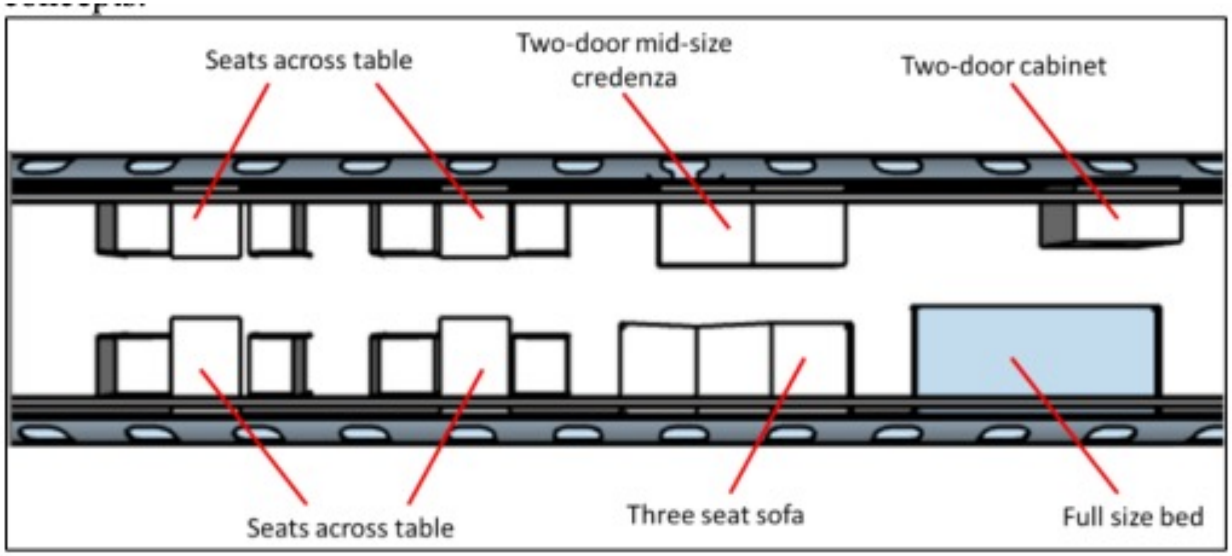


Figure 3. Partially sectioned top view with extended furniture pieces.

Figures 4 and Figure 5 illustrate the Open-on-Demand concept along the starboard and port sides of the partially sectioned cabin with zero-thickness furniture pieces. The area highlighted in yellow refers to the floor space the furniture pieces occupy in their extended forms.

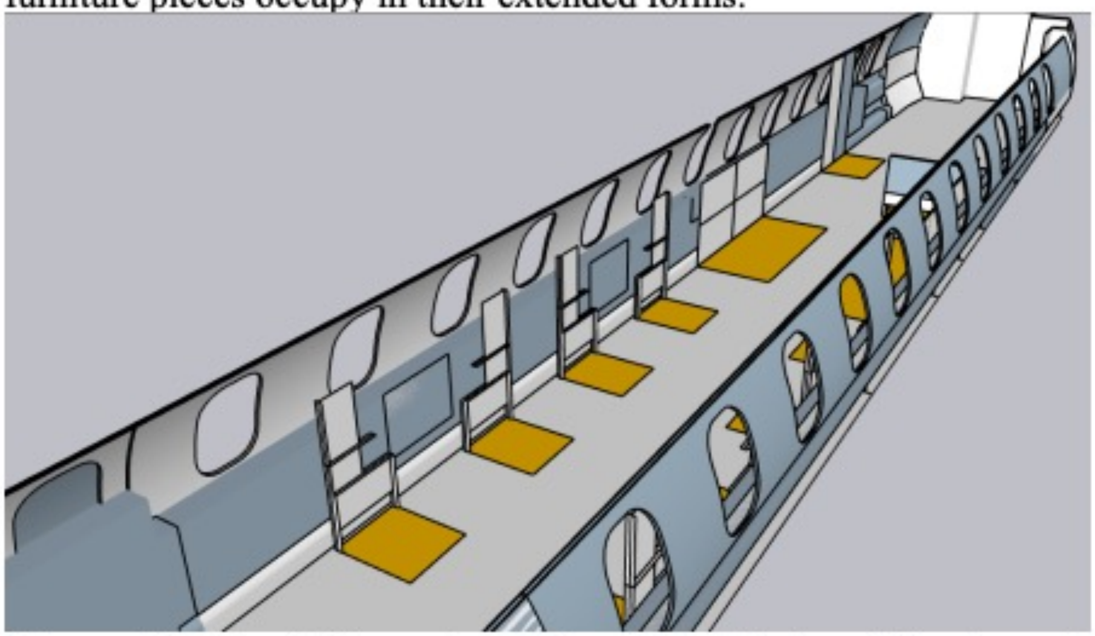


Figure 4. Starboard side partial section view with stowed furniture pieces.

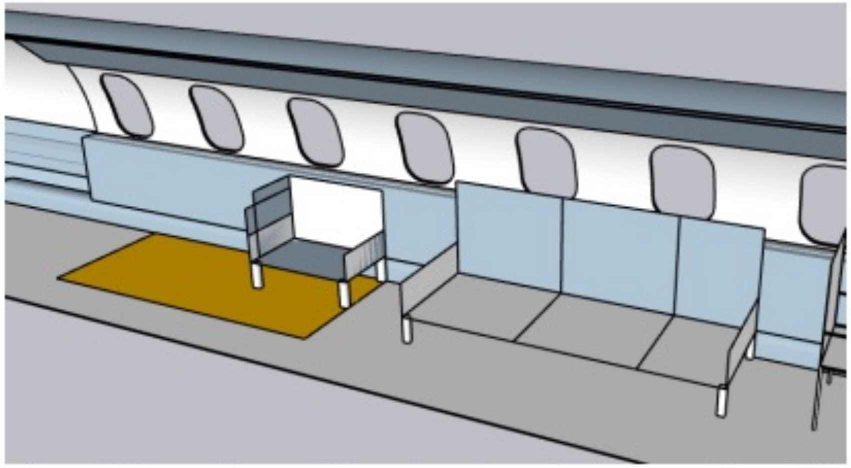


Figure 9. Port side partial section view of a bed reconfigured into a seat.

The furniture folding methodology can also be quantitively assessed to analyze advantages. A zero-thickness seat frame with measurements reflecting the lounge seat on a business jet was recreated using SketchUp 2020. Figure 10 illustrates an extended seat and stowed seat, following the furniture folding methodology, with a length of 27.25", width of 31.33" and height of 44.23" and new a length of 2", width of 31.33" and height of 44.23", respectively.

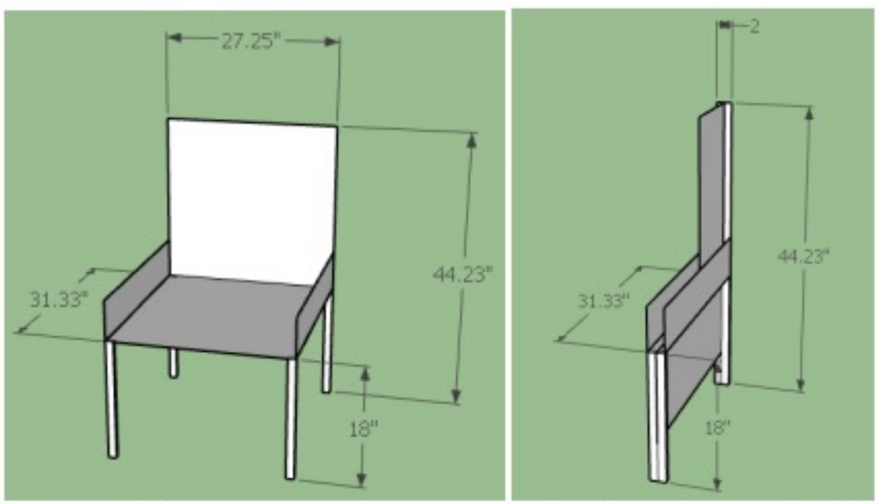
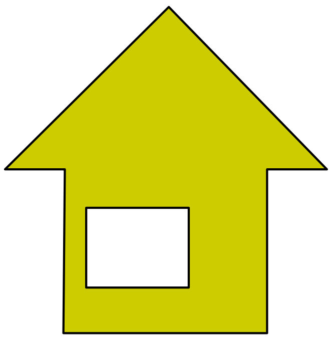


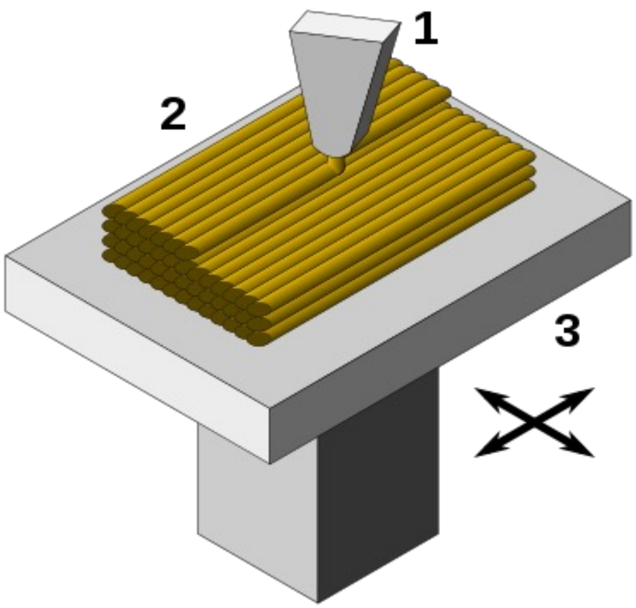
Figure 10. Recreation of an extended(left) and stowed(right) zero-thickness business jet lounge seat frame.

A cool decomposition for 3D printing

- How to decompose into few terrain-like parts?



Terrain-like part



Zero material waste for layer-based 3D printing

Pyramidal decomposition

- How to decompose into few terrain-like parts?

[Hu et al., *Siggraph Asia* 2014]

Pyramidal decomposition

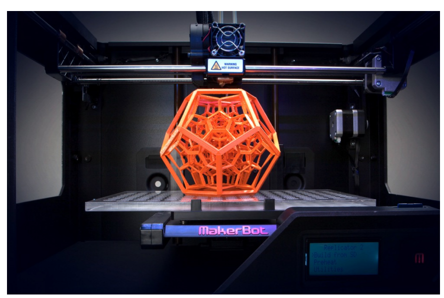
- How to decompose into few terrain-like parts?

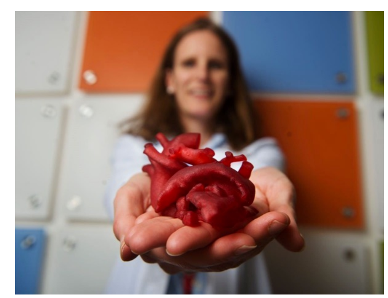
3D problem is provably NP-hard

Computer graphics is responsible for addressing the various 3D data challenges

3D printing may be a blessing

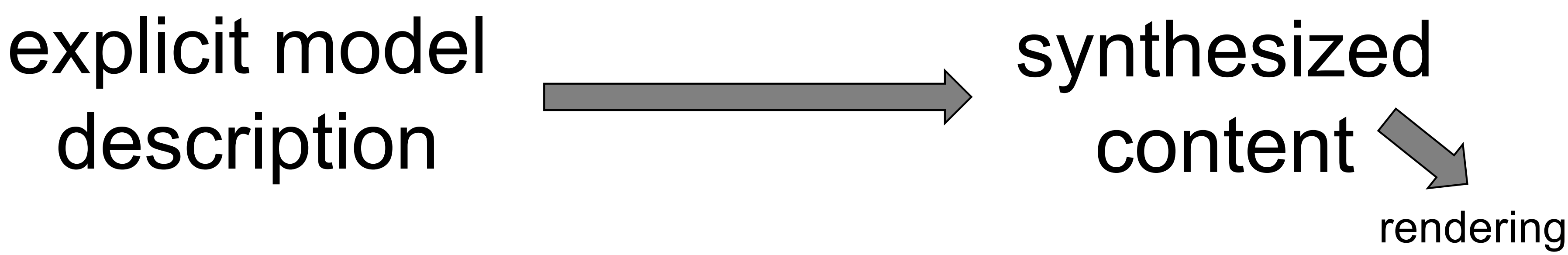
- Graphics likes 3D to be wanted & used everywhere
- The internet has not made 3D data ubiquitous as promised: remember VRML around 15 years ago?
- 3D printing just might!

New graphics

- Keep doing synthesis, but focus on modeling
- Synthesis of all visual contents, not just images



New graphics: no explicit model

- Keep doing synthesis, but focus on modeling
- Synthesis of all visual contents, not just images

~~explicit~~ model description → synthesized content → rendering

Model description is only abstract (e.g., texts or a sketch), hard to quantify (functional or creative), or unknown entirely (input = set of examples)

New graphics: novel content

- Synthesis and manipulation of ~~images~~

novel + visual contents

Implicit or abstract inputs, examples, … → novel content

New kinds of inputs

A rough sketch

New kinds of inputs

A rough sketch

One or more images

New kinds of inputs

A rough sketch

One or more images

Just some examples

Text-to-3D

“A baby bunny sitting on top of a stack of pancakes”
3D model generated from text [Zhu et al. 2023]

Text-driven 3D scene synthesis

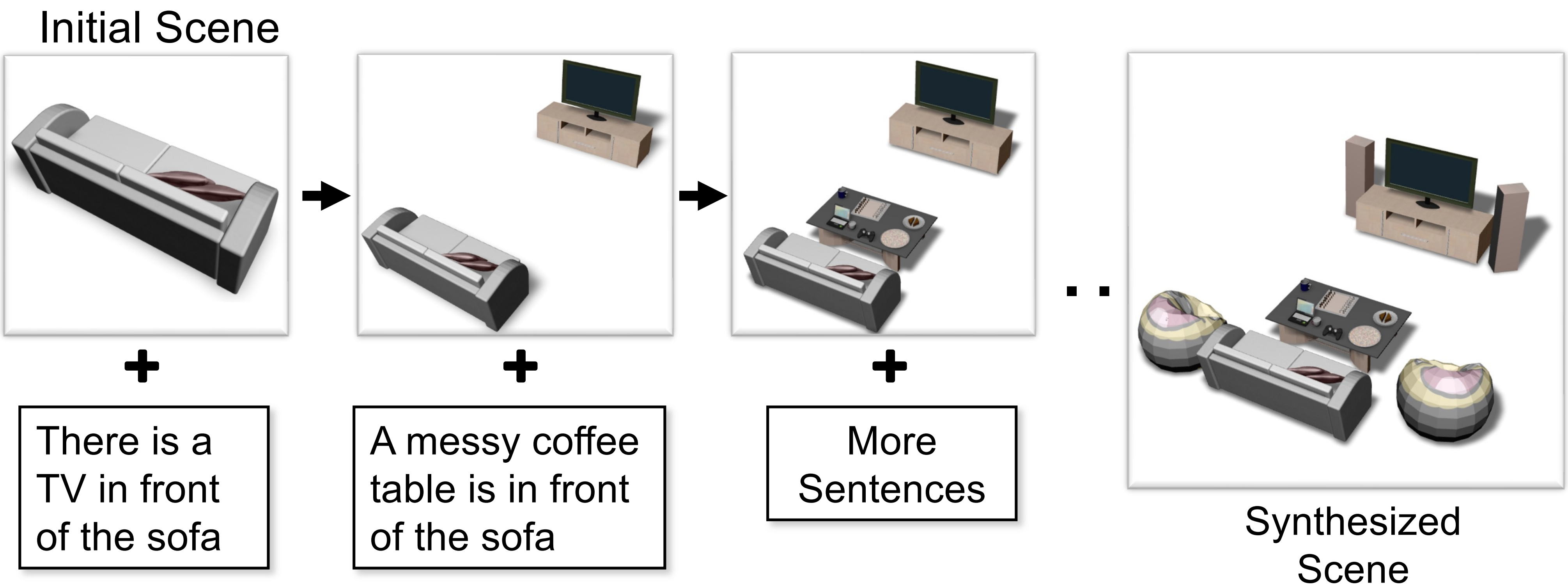
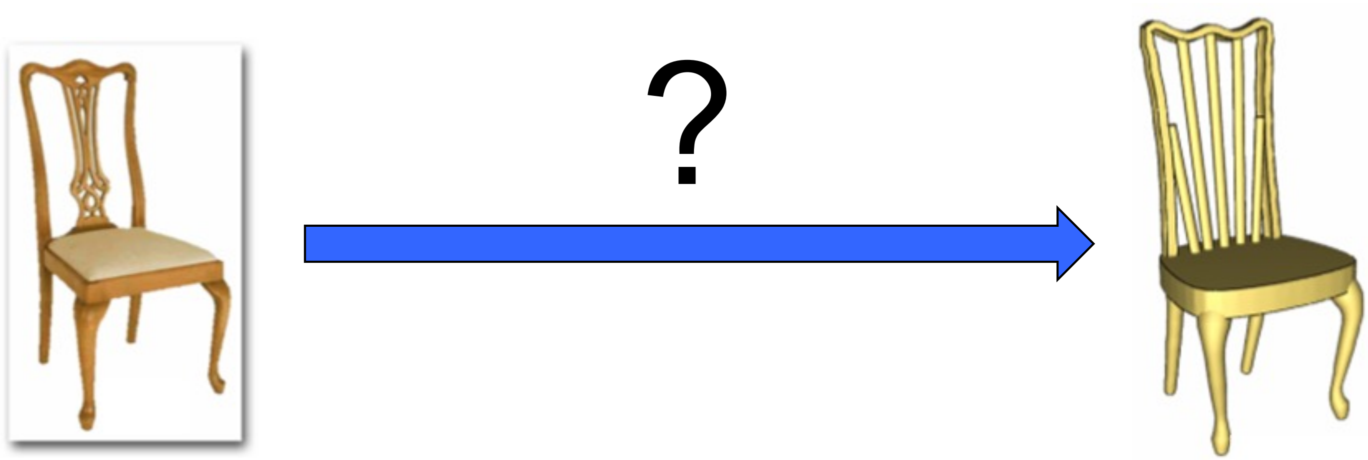


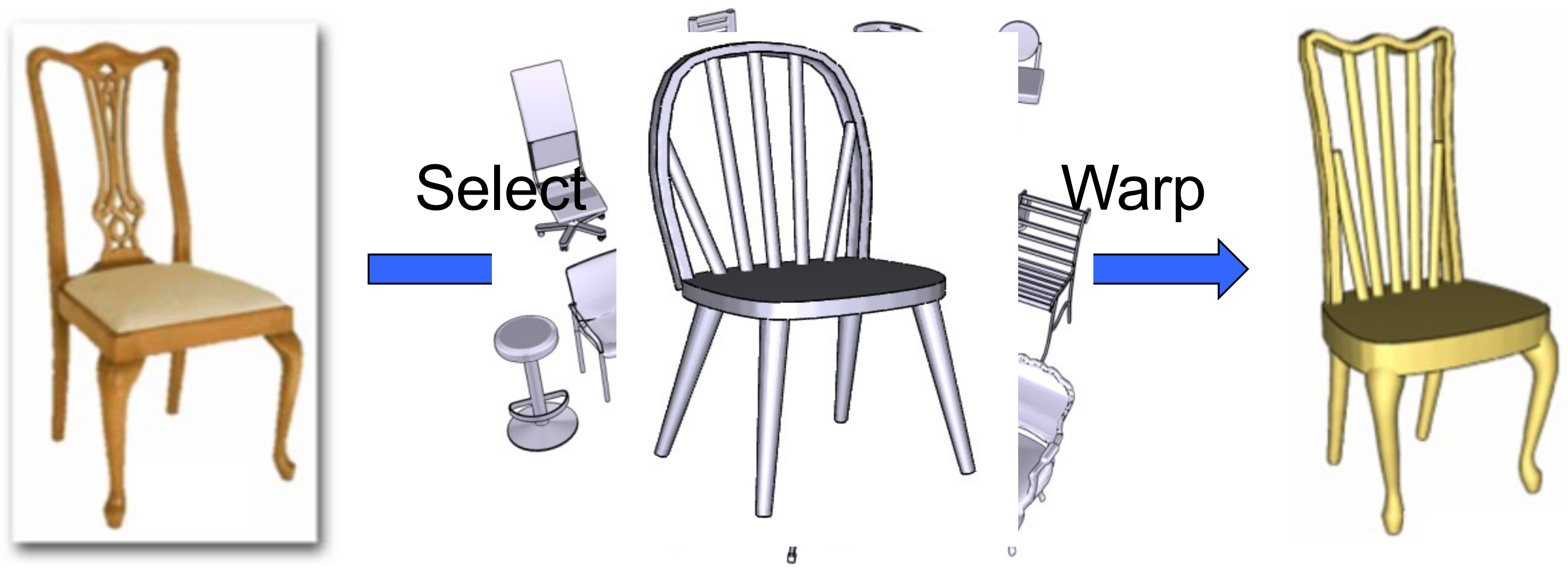
Photo-inspired modeling

- 3D model from a single photograph



Has to be data-driven

- Abstract inputs: ill-posed synthesis problem
- Needs extra knowledge, e.g., pre-existing dataset



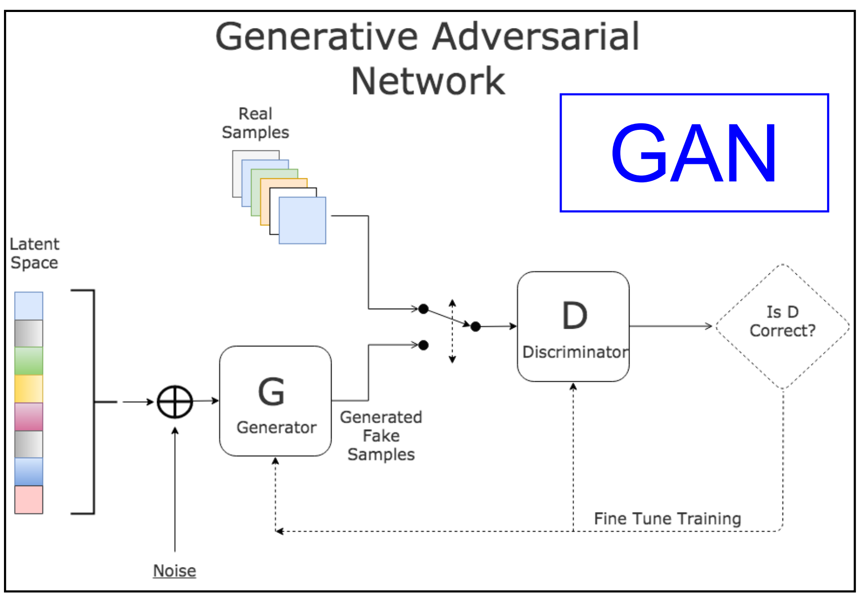
[Xu et al. *SIGGRAPH* 2011]

Example-based modeling

- Key: understand the set of examples by learning
- To infer commonality and diversity in the set

Inverse modeling

- Learn a generative model, e.g., from examples
- Apply the model forwardly, maybe with a random input, to synthesize novel contents



In the new graphics

We generate/synthesize objects/scenes that are

- Plausible: “What makes a chair a chair?”
- With the right style: “Essence of Gothic style?”
- Functional: “Shape vs. functional similarities?”
- Ergonomic: “How to quantify human comfort?”
- Creative: “What is a model of human creativity?”
- …

To generate/synthesize

2D/3D objects or scenes that are

- Plausible, stylistically compatible, aesthetically pleasing, functional, ergonomic, or creative, etc.

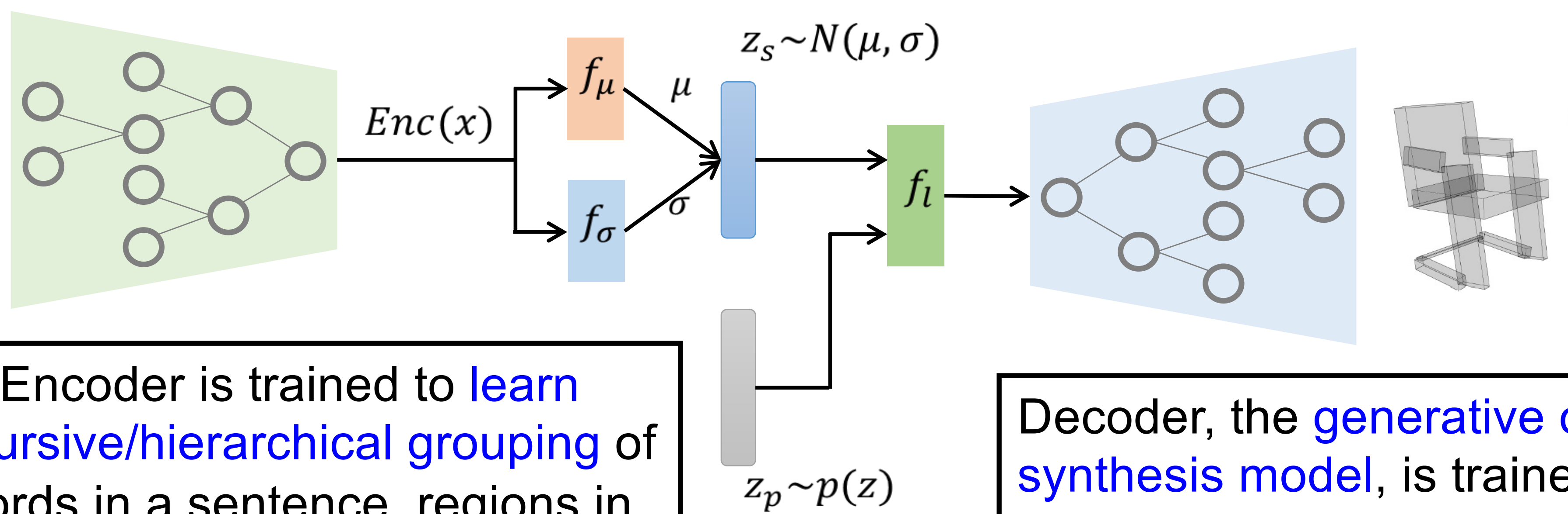
- We must first learn plausibility, style, function, etc.
- To generate from texts/sketches, we must learn the right mapping/regression model

Workflow of new graphics research

- Analysis to acquire understanding of
  - grouping/clustering patterns, object/scene composition, human activities, styles, functionality, creativity, etc.
- Synthesis of images, shapes, scenes via
  - interactive modeling, genetic algorithm, statistic models, deep regression and generative neural networks, etc.

Example: generative structural reps

- Generative autoencoders via recursive neural nets



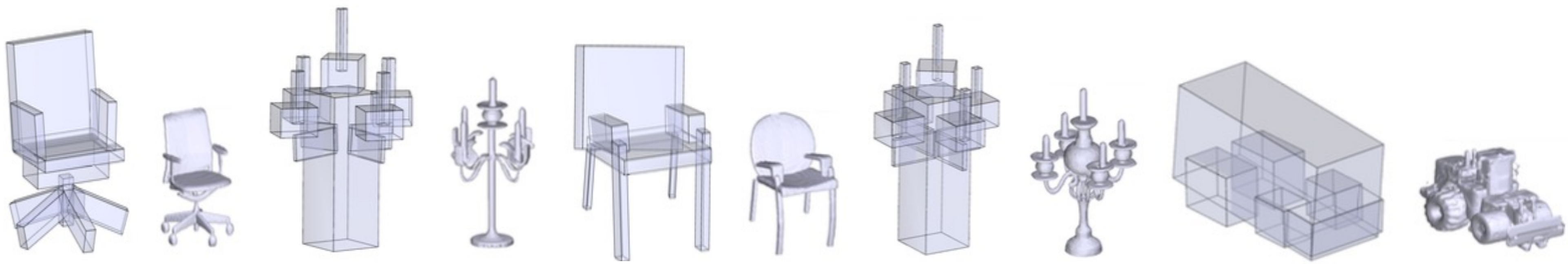
Encoder is trained to learn recursive/hierarchical grouping of words in a sentence, regions in an image, parts in a 3D shape, or objects in an indoor scenes

Decoder, the generative or synthesis model, is trained to convert a random code into a hierarchy

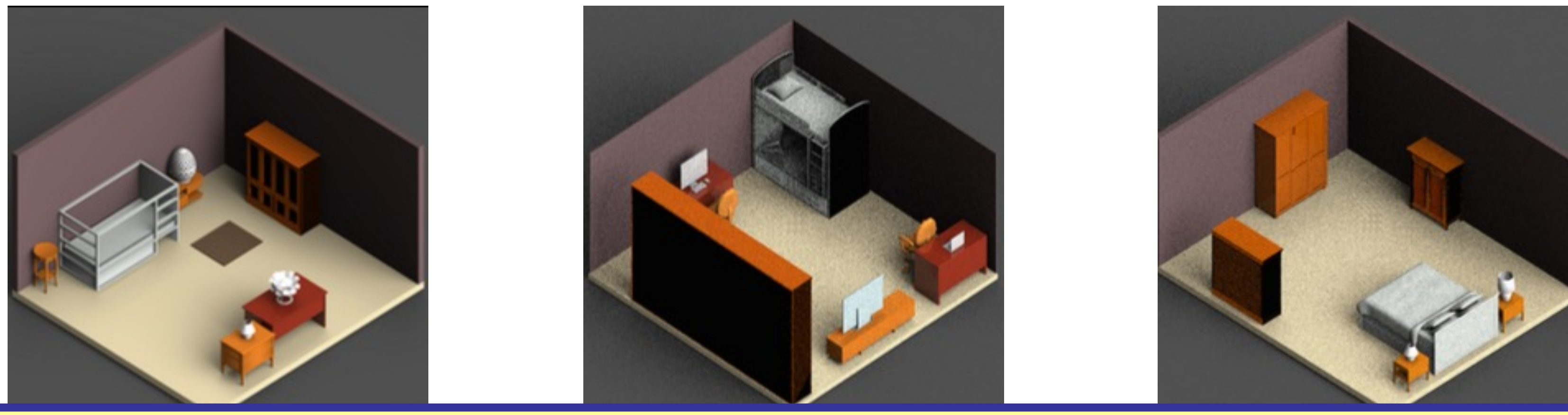
GRASS: Generative Recursive Autoencoders for Shape Structures [SIG 2017]

Example: generative structural reps

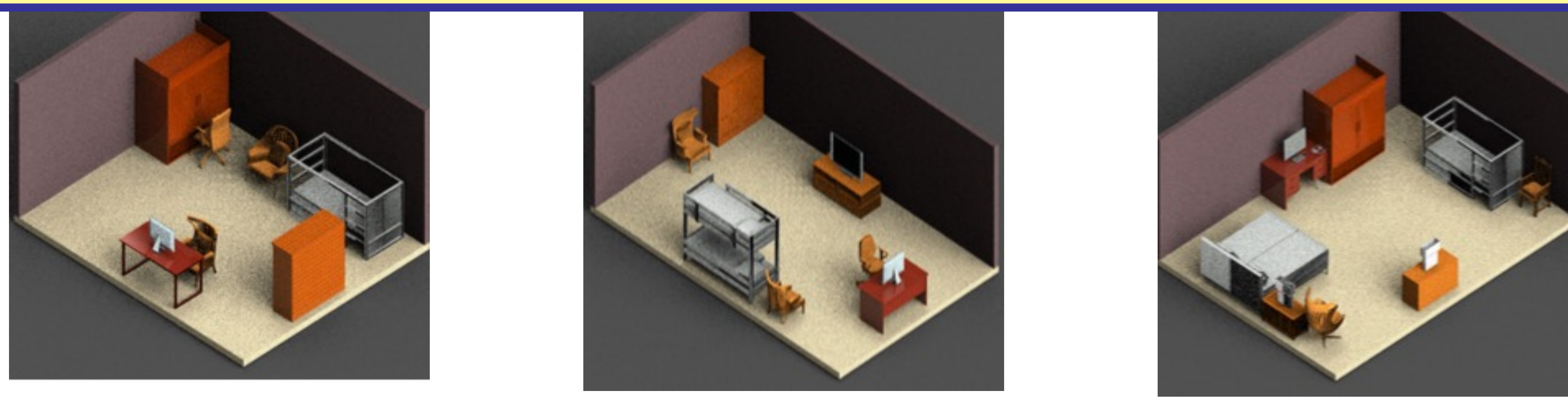
- Combine autoencoder with GAN: VAE-GAN
- Structure-aware; coarse-to-fine; clean parts; high res



Example: scenes from random codes



Takes less than one second to generate a 3D scene!



GRAINS: Generative Recursive Autoencoders for INdoor Scenes [2018]

New graphics: not forward problem

- Inverse analyses and learning generative models
- Keying on shape/scene understanding
- Only with a good understanding of a shape/scene category (“bicycle” or “kitchen”) can one recreate!

Important problems in new graphics

- Modeling from abstract description
- Modeling from few examples
- Inverse procedural modeling
- Learning generative neural networks

Knowledge, learning, and data
play the key roles!

Our new view of graphics

- Wikipedia was already catching up:
  - Something I hid: Computer graphics = methods for digitally synthesizing and manipulating visual content
- From image production to all (3D) visual content

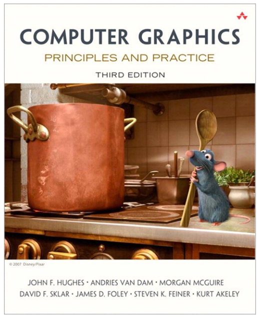
Novelty

of the synthesized content is the BIG challenge!

Current graphics and computer vision

- Hughes, van Dam, et al.:
  - "Much of current research in graphics is in methods for creating geometric models, methods for representing surface reflectance, the animation of scenes …, and in recent years, an increasing integration of techniques from computer vision."

------ *page 2 of*



Computer graphics vs. vision again

- Shape understanding and inverse modeling are very much “vision-like” research problems
- So, graphics is “catching up” ☺
- But could we do more?

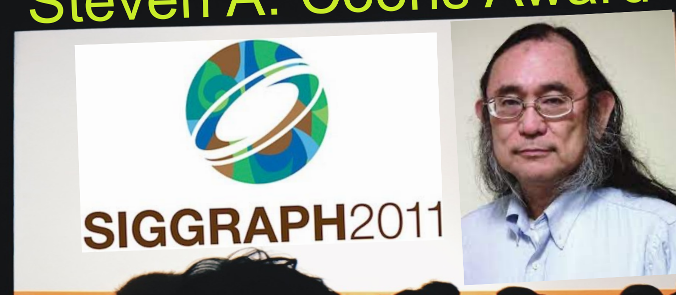

Steven A. Coons Award
SIGGRAPH2011

Jim Kajiya: What human capabilities does each CS discipline try to enhance/replace?

Artificial intelligence:
human intelligence

Computer vision:
pattern recognition

Steven A. Coons Award



What about computer graphics?

Human imagination!

Graphics and imagination

- Think of the various VFX we see in films and games
- Think of the VR/AR/MR CG has helped create

Computer graphics allows our imagination to be realized into (virtual) reality!
It allows a mental concept to turn into a digital representation, and now fabricated!

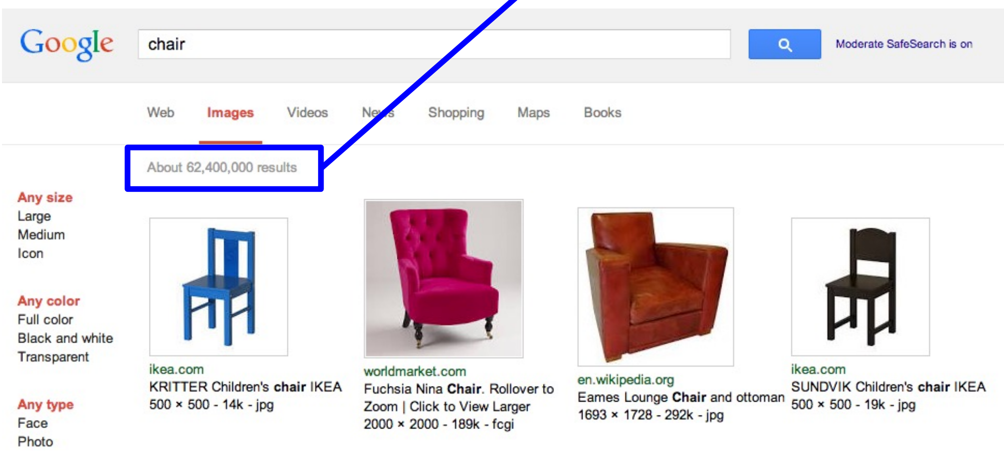
Still a long way to go

- Only scratching the surface in the new graphics
- Smart ideas: data-driven, data reuse, co-analysis, supervised learning, active learning, etc.
- Future of modeling in computer graphics

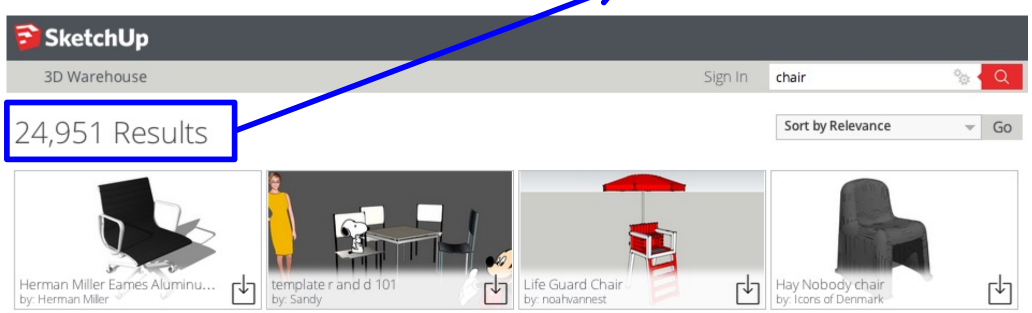
Data + knowledge + learning

A new 3D data challenge

Google image search for chair: 64,000,000 results

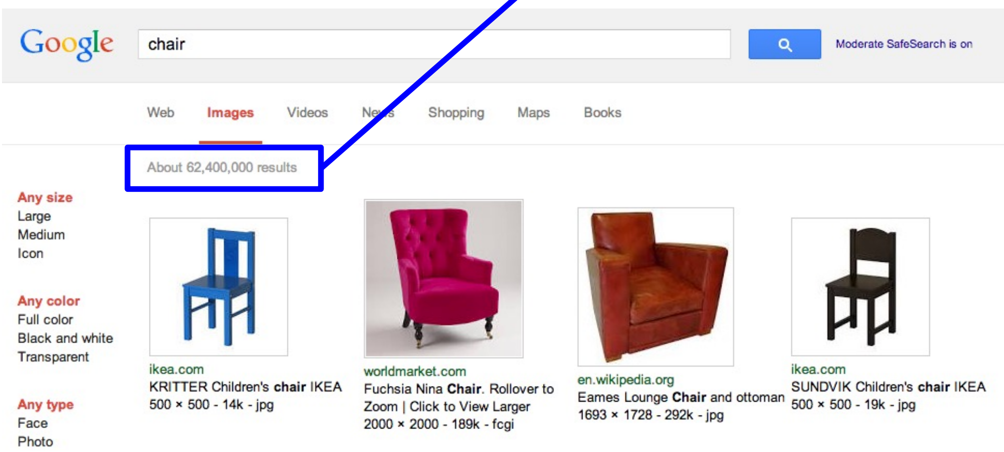


3D Warehouse: 24,951 results



No “Big 3D Data” yet

Google image search for chair: 64,000,000 results



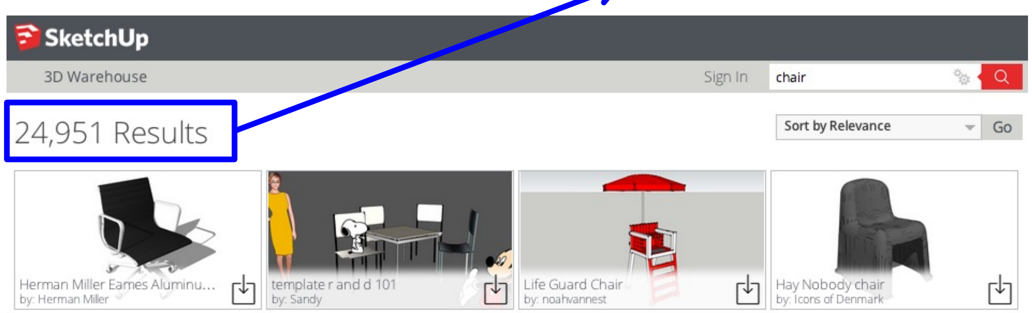
- Bicycles

  29,900,000 vs. 1,225

- Strollers

  5,070,000 vs. 36

3D Warehouse: 24,951 results



Problems with “small 3D data”?

- Lack of knowledge for learning-based 3D analyses
- Lack of examples for example-driven 3D syntheses
- Small data is *the* detriment to

Data + knowledge + learning

To fix the "small 3D data" problem

- Need to synthesize more and more 3D models!
- Not only volume, but variation, variety, and novelty!

Novelty of synthesized content may enhance knowledge!
Computer graphics is responsible for producing such Big 3D Data

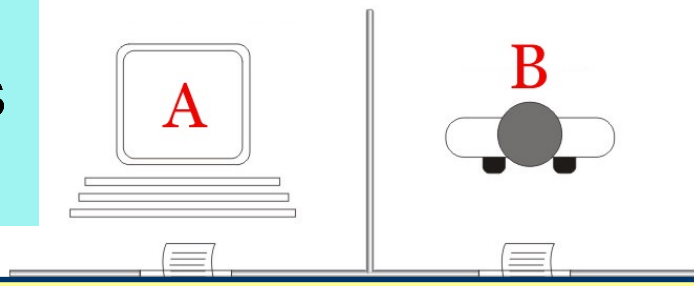
What is a machine becoming human?

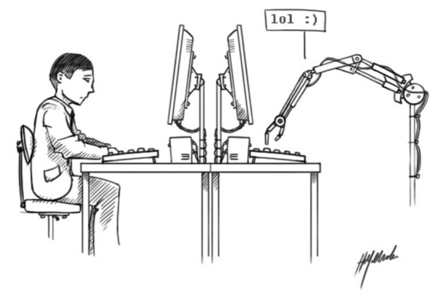
What about AI?

When is a machine becoming human?

- Well-known Turing test: indistinguishability between human and machine in natural conversation

Multiple human judges vote who is human/machine

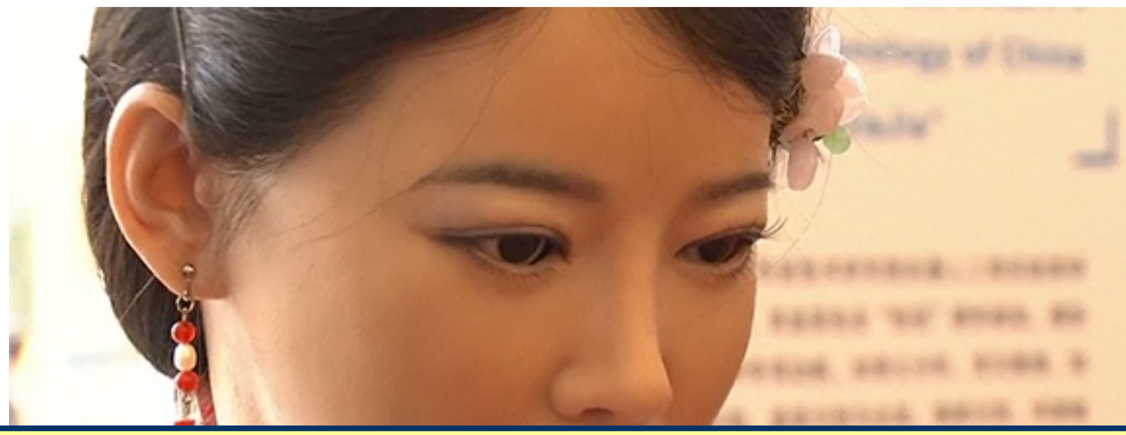




Turing (1950’s) predicted the test would be passed around year 2000. An easy version of the test was passed in 2014 by *Eugene*, a ChatBot.

When is a machine becoming human?

- Total Turing test: machines linguistically and physically indistinguishable from a human



Hans Moravec (1999): Total Turing Test to be passed by the year 2040

Is this Turing test too easy?

- Ada Lovelace (1815-1852)
  - Pre-dates Turing (1912 – 1954)
  - Worked on world's first computer
  - AKA: the first computer programmer

Computers can't create anything (Humans can!). Creation requires originality. But computers originate nothing; they only do that what we order them, via programs, to do.
- Ada Lovelace

A harder test: Lovelace Test

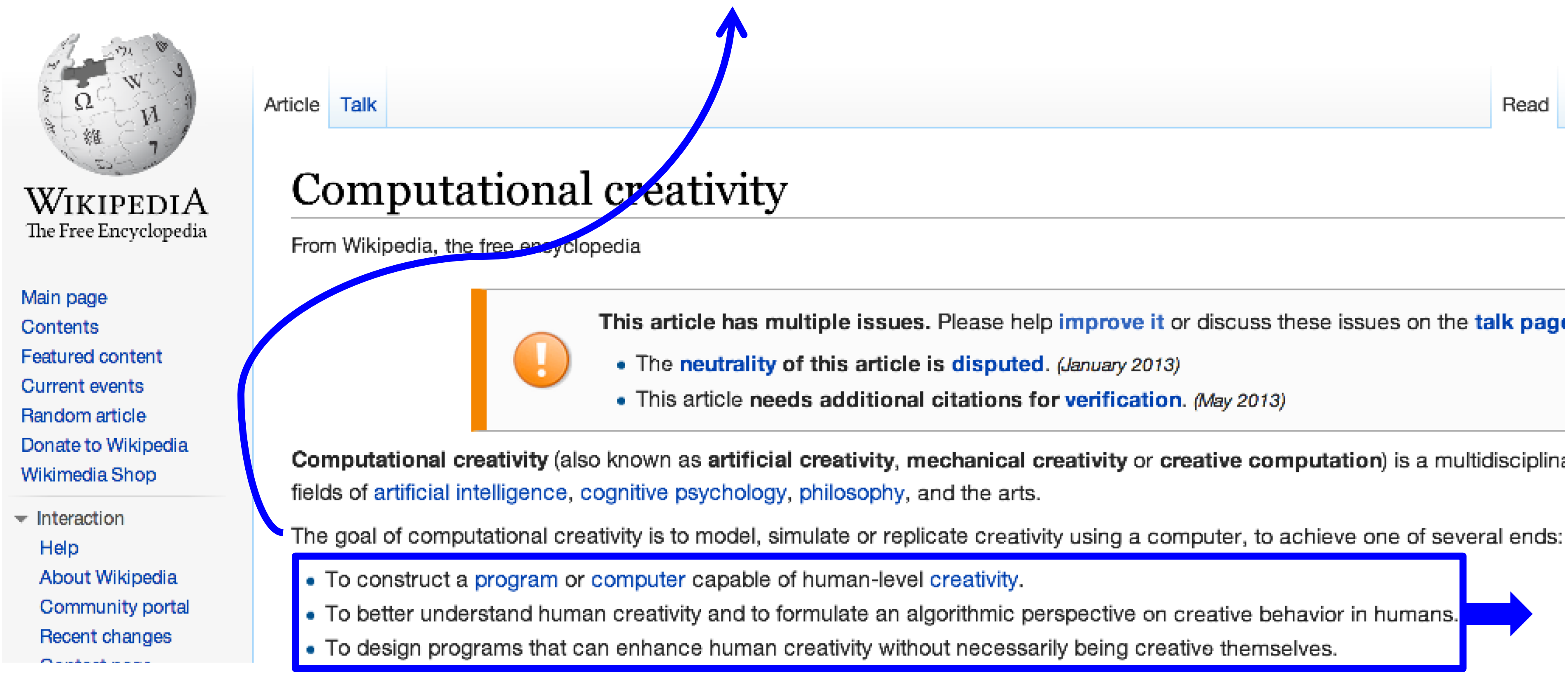
- Test on machines' ability to create an artifact
  - e.g., a story, poem, painting, or a 3D shape
- Test or judging criterion can vary

Key message: What really separates humans from machines is not the ability to make conversation, but the ability to create!

Creation and synthesis of visual content is the goal of computer graphics!

Computational creativity

- Goal: model or simulate creativity using a computer



Goals of computational creativity

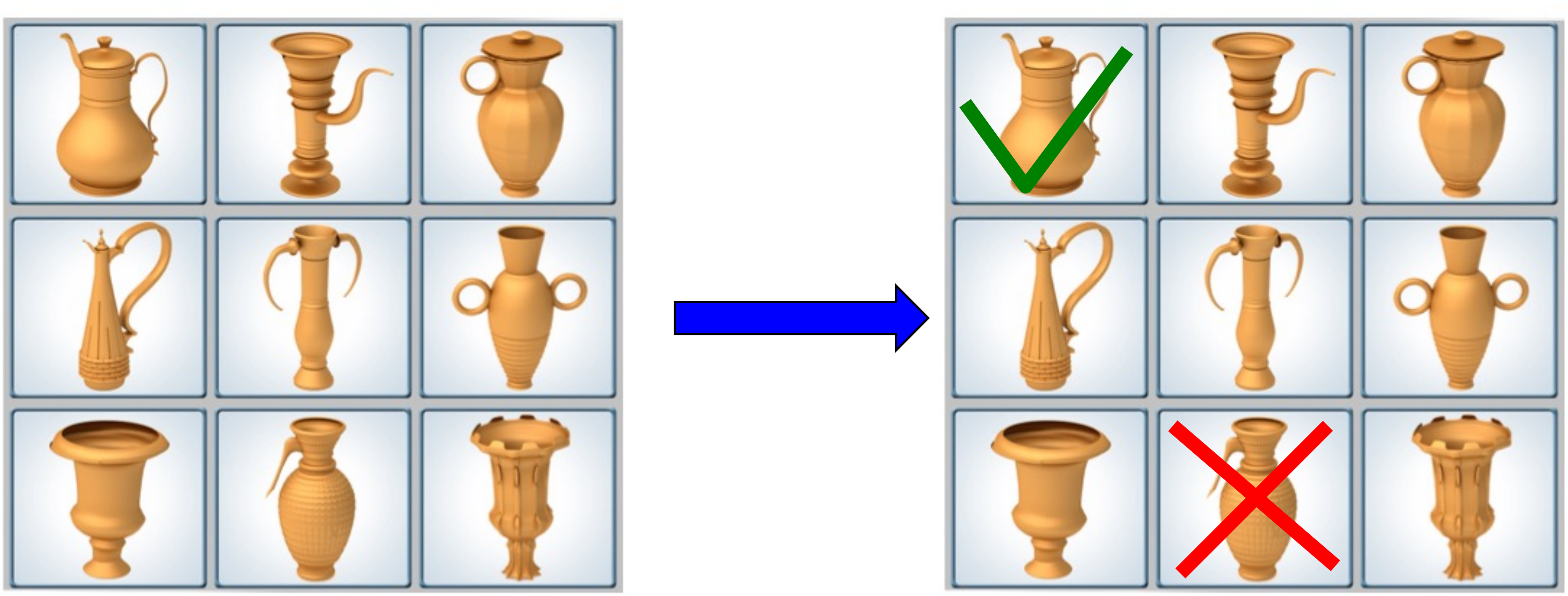
*** Construct a program capable of human creativity

** Understand creativity and formulate an algorithmic perspective on creative behavior in humans

* Design a program which may enhance human creativity without the program being creative itself

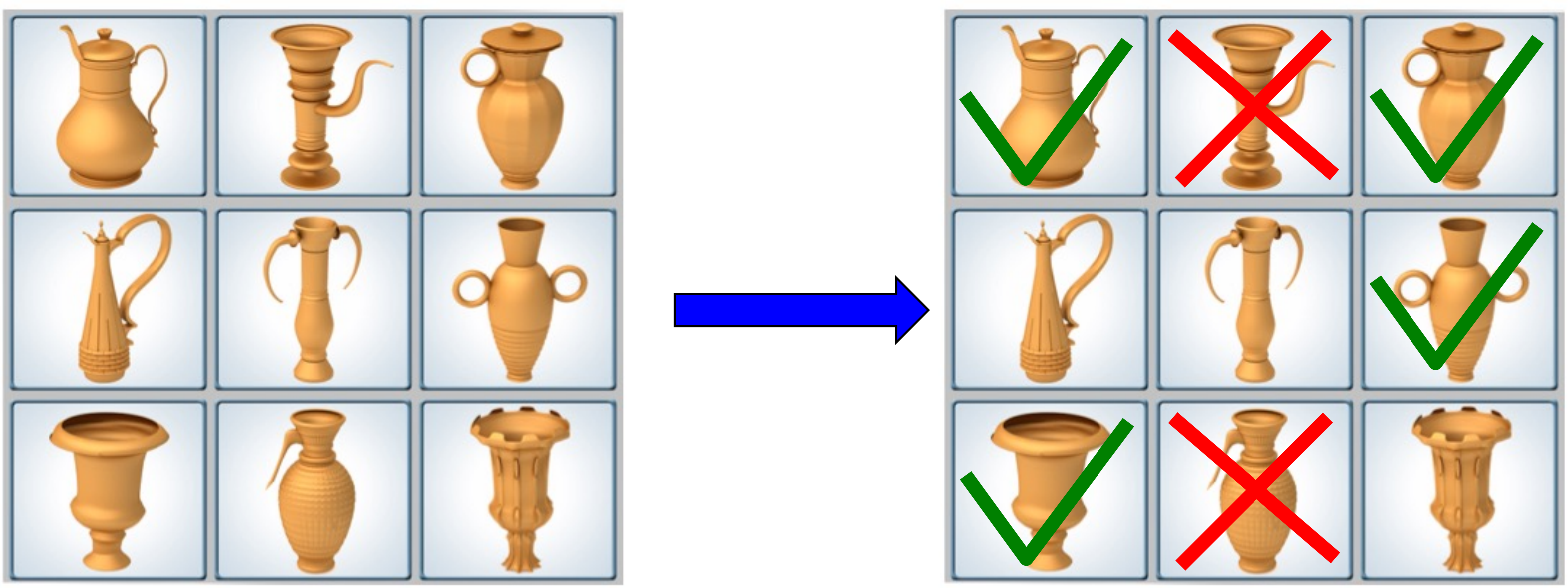
Creative 3D modeling

- Creativity: machines stochastically generate models
- Has to be controlled



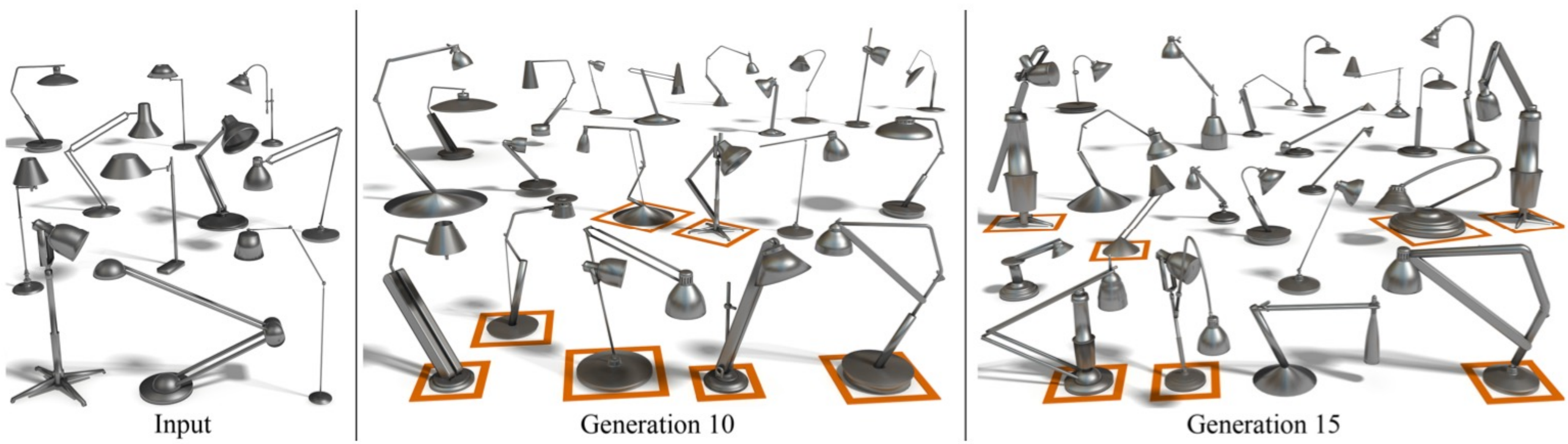
Creative 3D modeling

- Creativity: machines stochastically generate models
- Control by humans operating on a "design gallery"



Creative 3D modeling via evolution

- Evolve an entire set (initial population) to obtain generations of fit and diverse new creations



[Xu et al. *SIGGRAPH* 2012]

Creative 3D modeling

- Allows creative generation of novel 3D contents

Genetic algorithm + Interactive modeling

Very far from an intelligent machine that is creative

Machine to generate creative logos?

What can we do now?

[Tanveer et al. *ICCV* 2023]

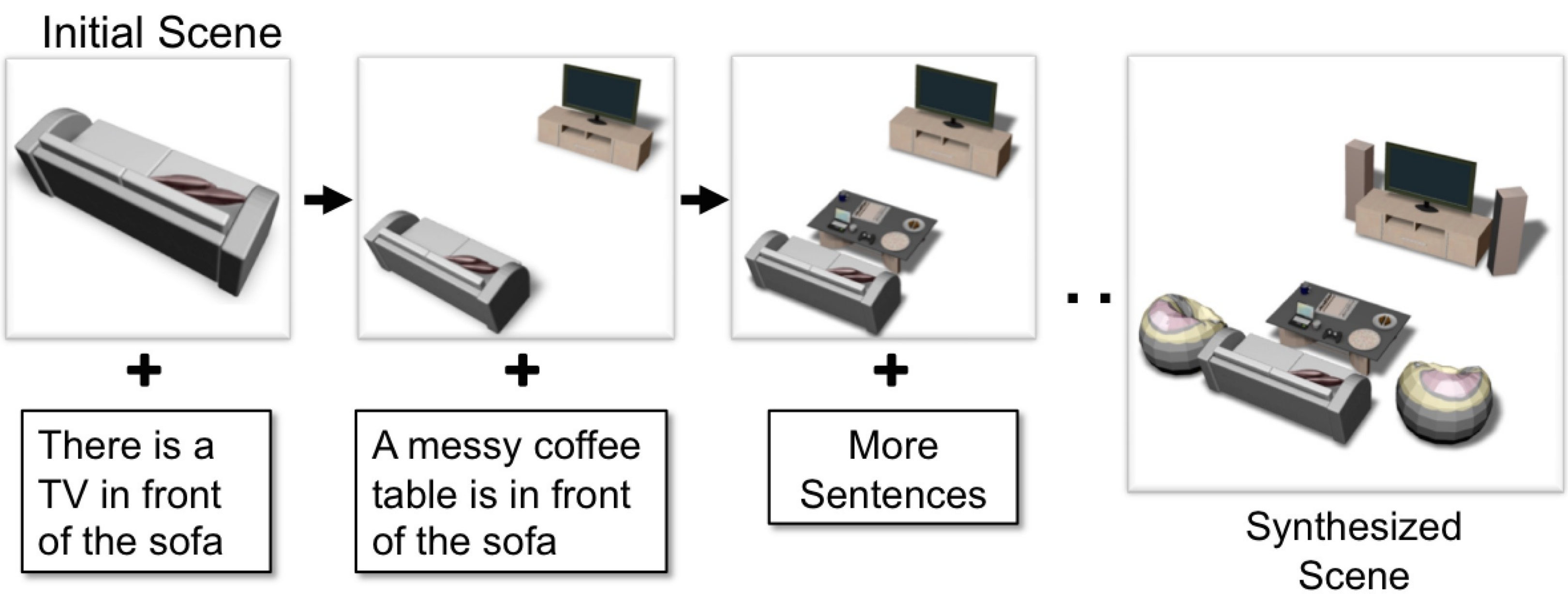
Creativity is not a talent, it is a way of operating.

— John Cleese

Graphics in the age of AI and Big data

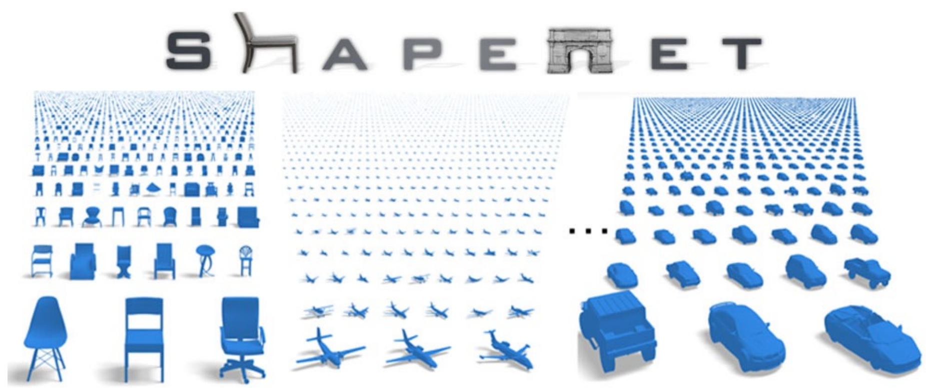
Graphics is responsible for

- Addressing the various 3D data challenges: acquisition, modeling, interaction, etc.

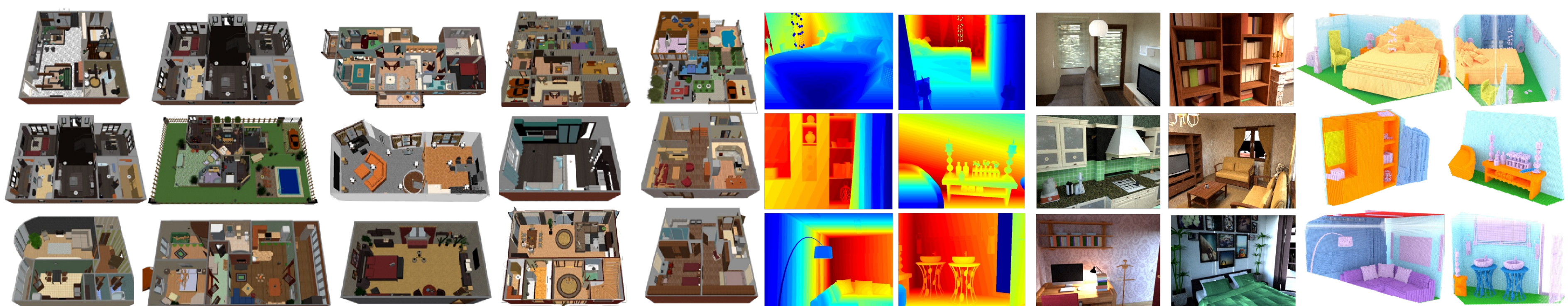


Graphics is responsible for

- Producing BIG 3D data



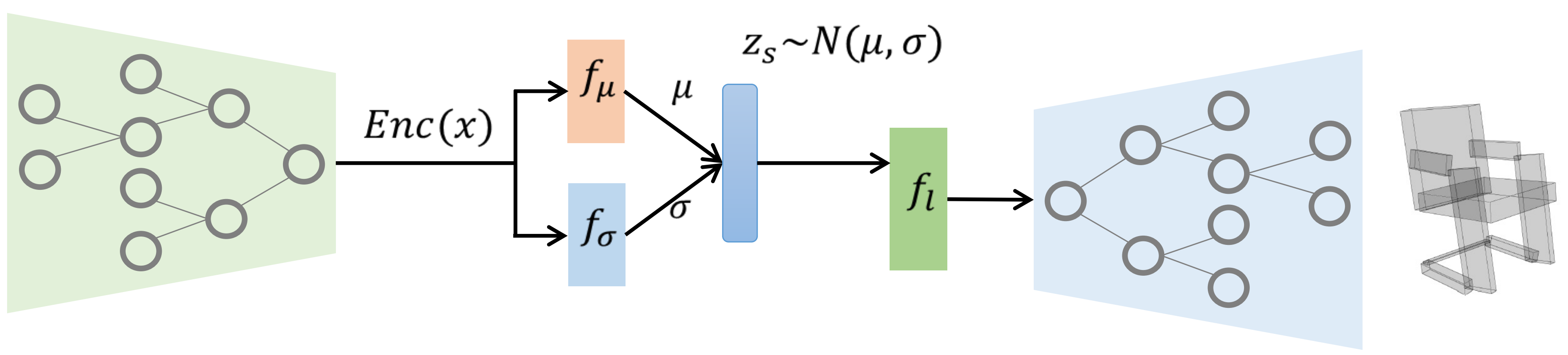
ScanNET



SUNCG dataset Depth Physical based rendering Volumetric ground truth

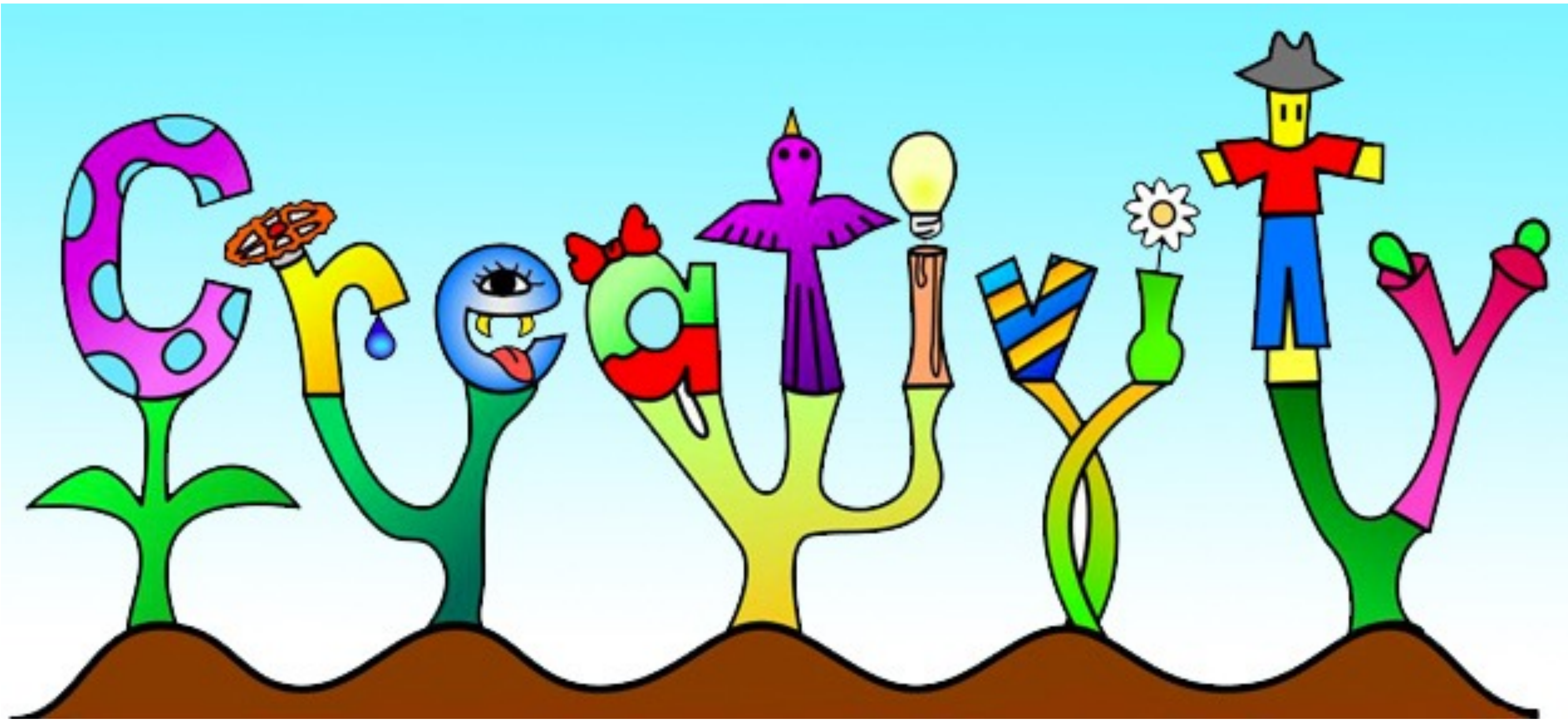
Graphics is responsible for

- Training machines and neural networks capable of generating (novel) 3D content from abstract, implicit descriptions, sets of examples, etc.



Graphics is responsible for

- Realizing and enhancing human imagination and



New graphics: synthesis challenges

- No explicit model description
- Synthesize novel 3D content
- Synthesize Big 3D Data
  — 4 V's: Volume + Variation + Variety + NoVelty
- Synthesize creative 3D content

We are only scratching the surface!