CS425 GAME PROGRAMMING

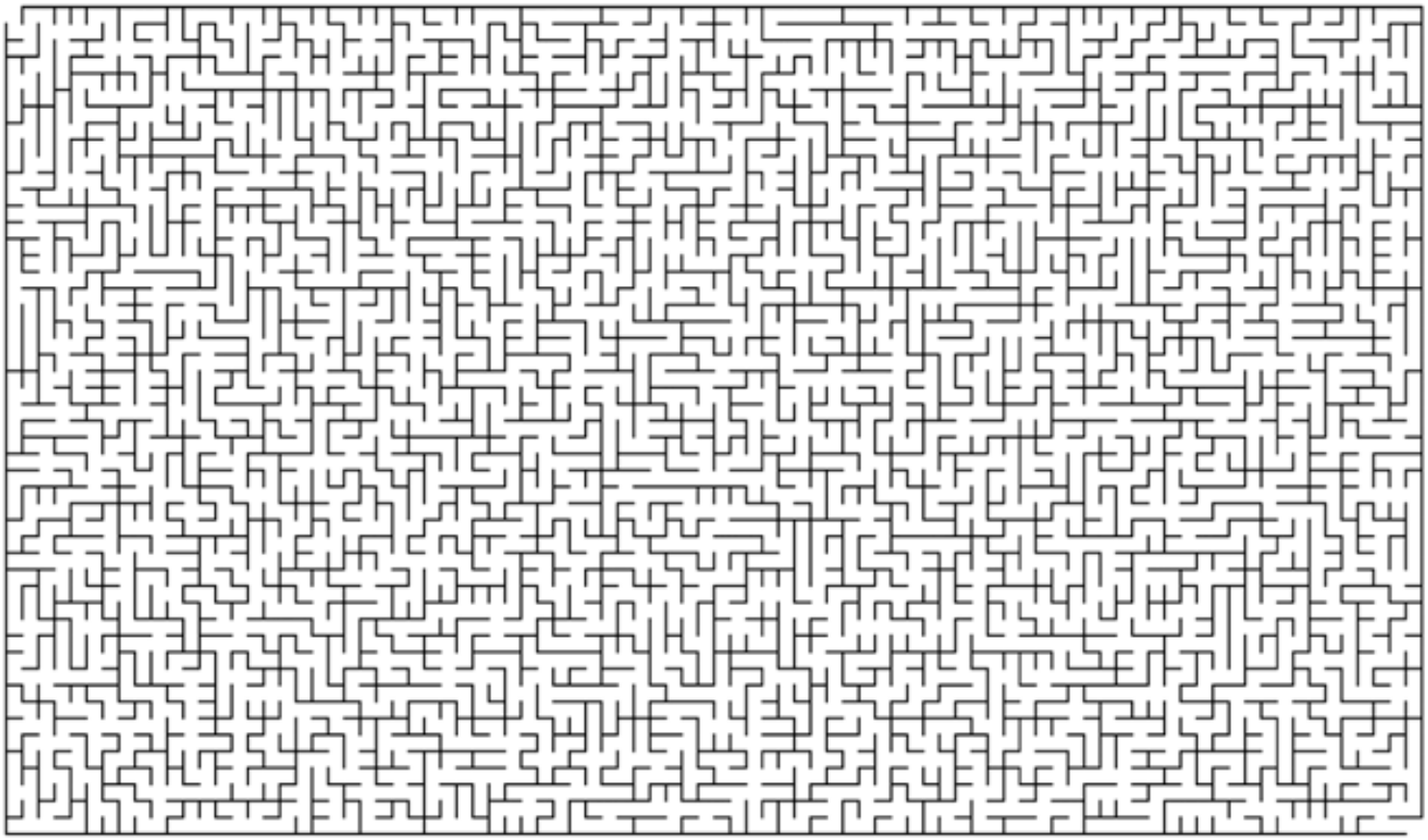
Procedural Modeling

Procedural Modeling

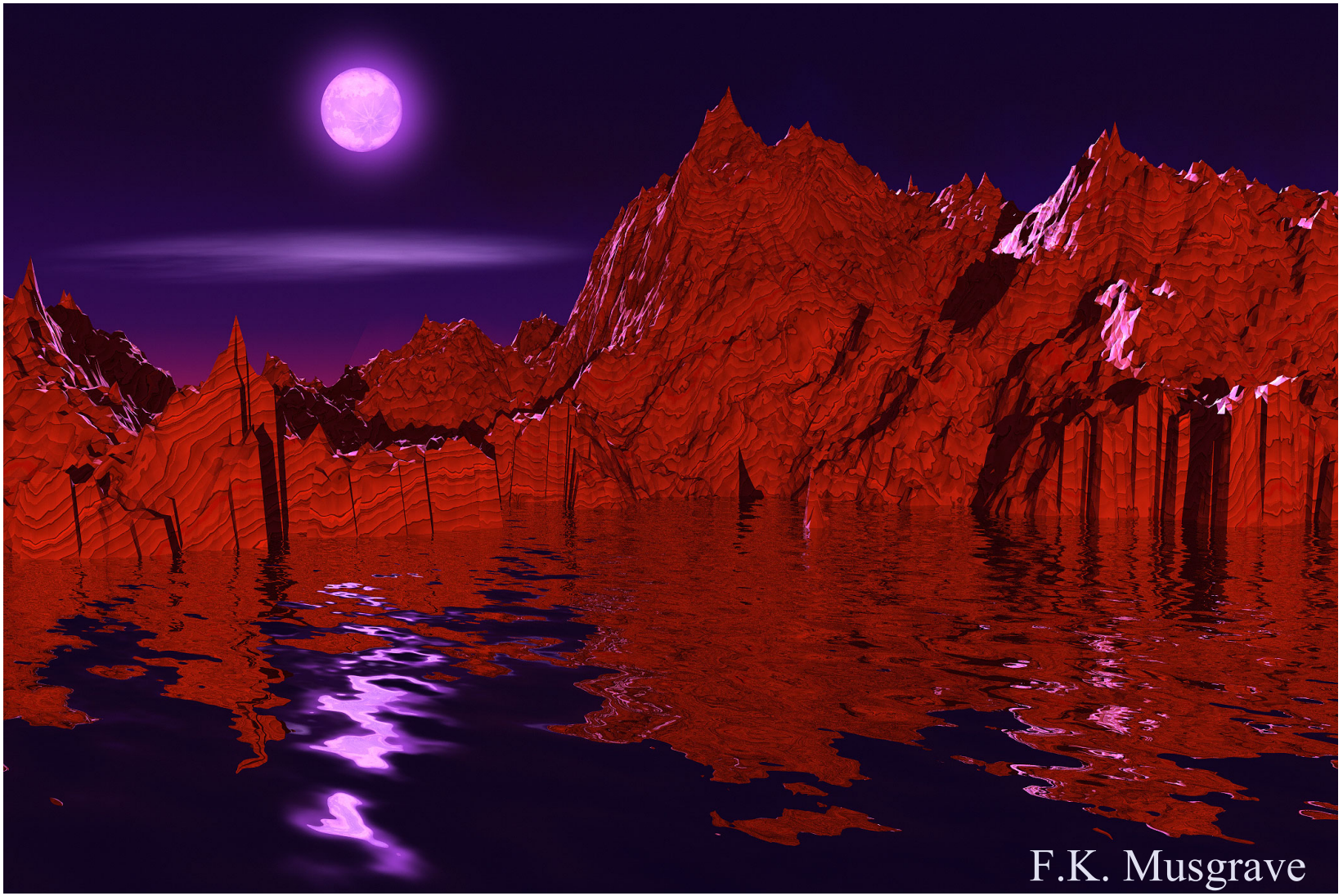
- Goal:
  - Describe 3D models algorithmically
- Best for models resulting from ...
  - Repeating processes
  - Self-similar processes
  - Random processes
- Advantages:
  - Automatic generation
  - Concise representation
  - Parameterized classes of models

Map Creation

- What are the criteria for creating a map/maze/dungeon like this?



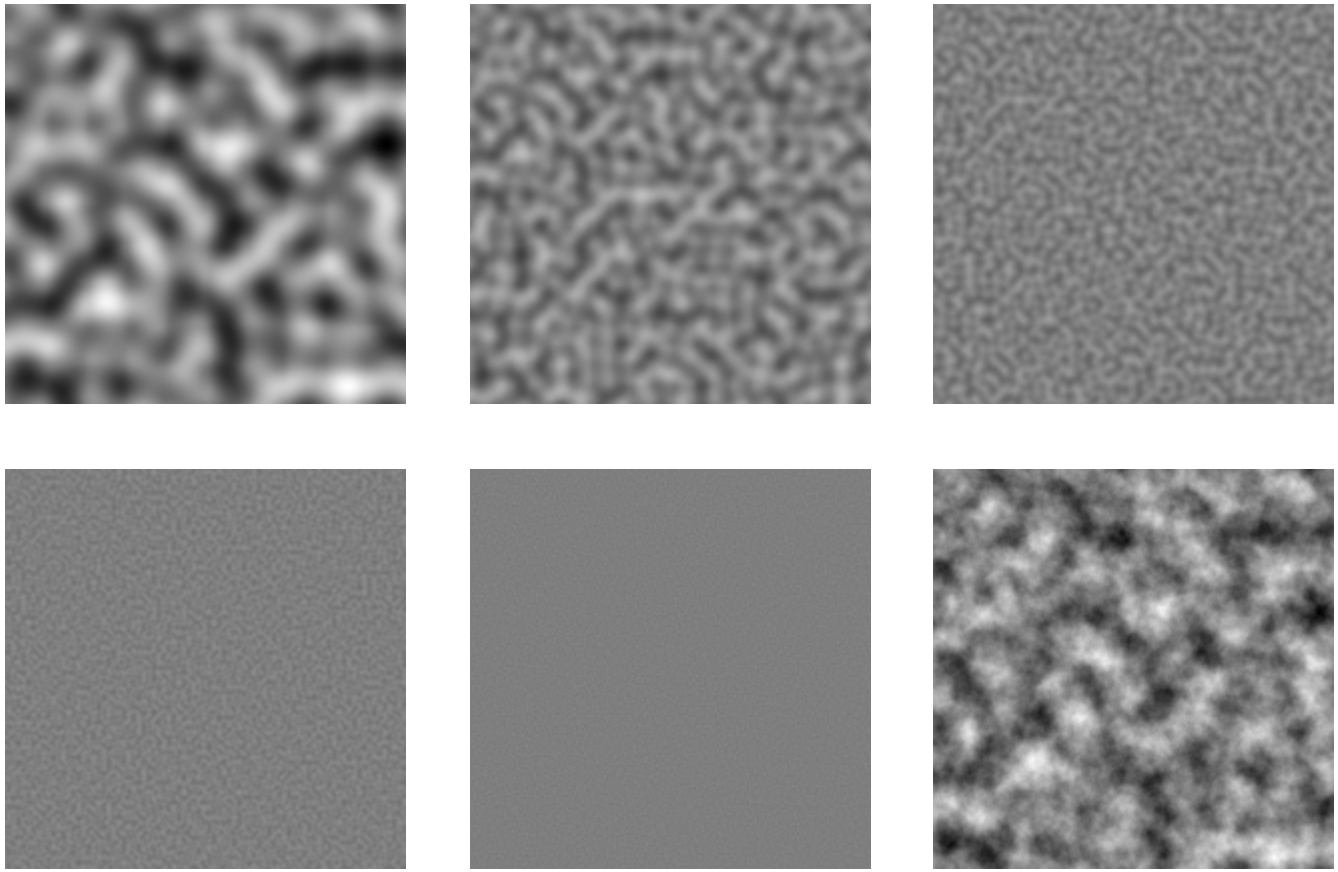
Terrain Example



Perlin Noises in 2-D

See also http://flafla2.github.io/2014/08/09/perlinnoise.html

- Natural looking
- Gradient based interpolation



Example: Seashells

- Create 3D polygonal surface models of seashells

"Modeling Seashells,"
Deborah Fowler, Hans Meinhardt,
and Przemyslaw Prusinkiewicz,
Computer Graphics (SIGGRAPH 92),
Chicago, Illinois, July, 1992, p 379-387.

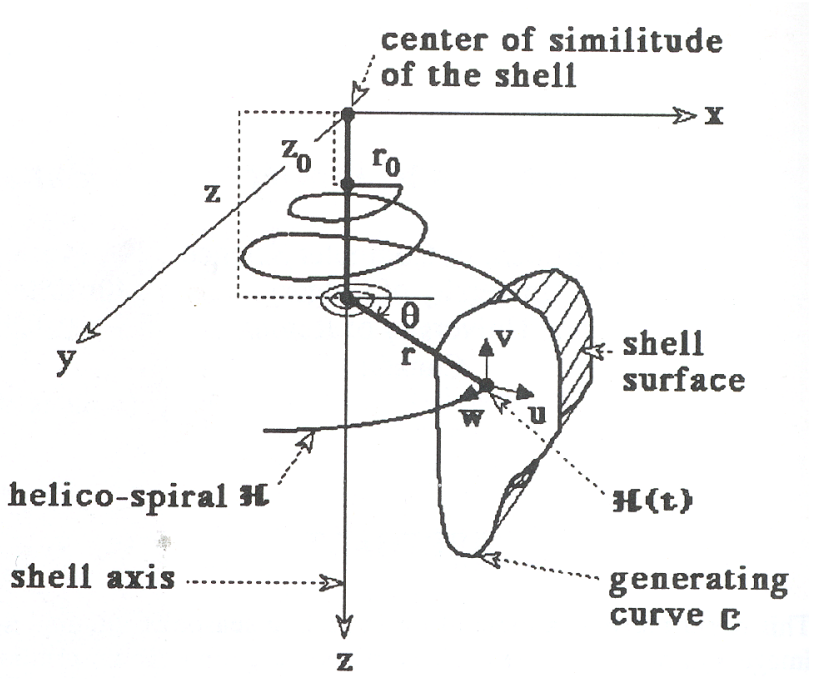
Fowler et al. Figure 7

Example: Seashells

- Sweep generating curve around helico-spiral axis

Helico-spiral definition:

$$\Theta_{i+1} = \Theta_i + \Delta\Theta$$
$$\lambda_{i+1} = r_i \lambda_r$$
$$z_{i+1} = z_i \lambda_z$$



Fowler et al. Figure 1

Example: Seashells

- Generate different shells by varying parameters

Different helico-spirals

Fowler et al. Figure 2

Example: Seashells

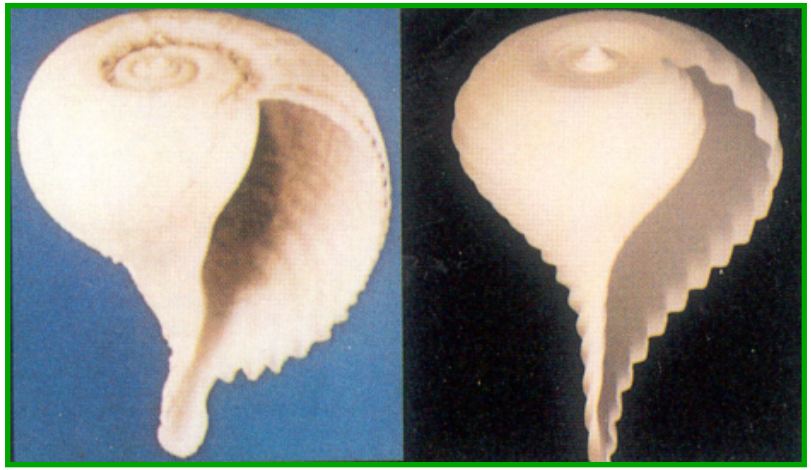
- Generate different shells by varying parameters

Different generating curves

Fowler et al. Figure 3

Example: Seashells

Generate many interesting shells with a simple procedural model!



Fowler et al. Figures 4,5,7

Fractals

- Useful for describing natural 3D phenomenon
  - Terrain
  - Plants
  - Clouds
  - Water
  - Feathers
  - Fur
  - etc.

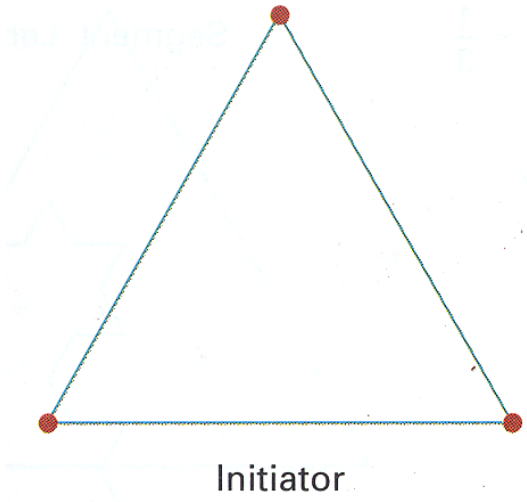
H&B Figure 10.80

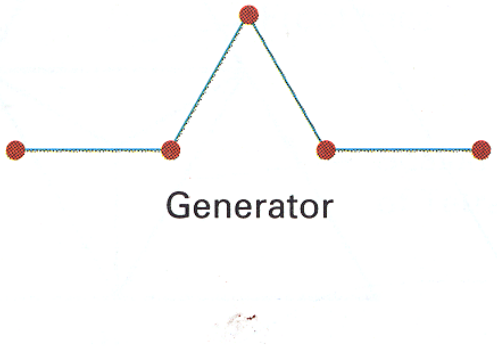
Fractal Generation

- **Deterministically** self-similar fractals
  - Parts are scaled copies of original
- **Statistically** self-similar fractals
  - Parts have same statistical properties as original

Deterministic Fractal Generation

- General procedure:
  - Initiator: start with a simple shape
  - Generator: replace subparts with scaled copy of original

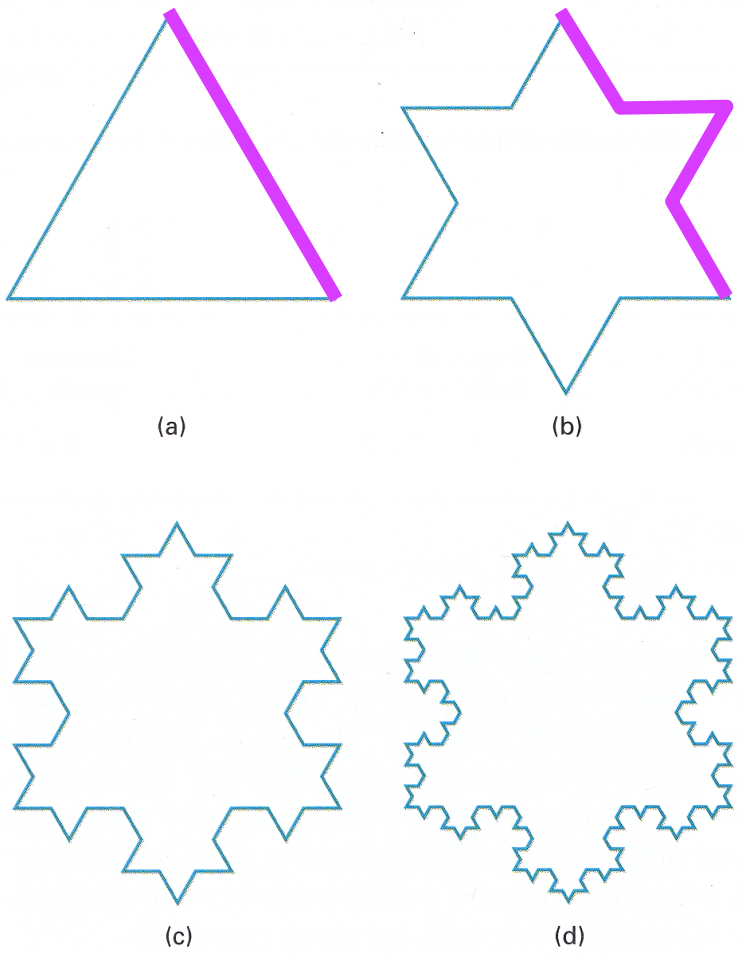




H&B Figure 10.68

Deterministic Fractal Generation

- Apply generator repeatedly



Koch Curve

H&B Figure 10.69

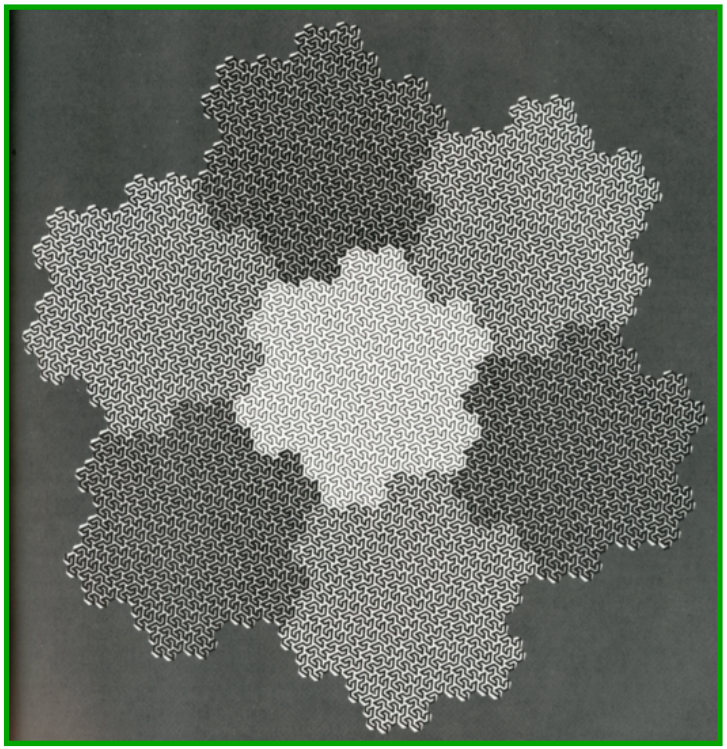
Deterministic Fractal Generation

- Useful for creating interesting shapes!

Mandelbrot Figure X

Deterministic Fractal Generation

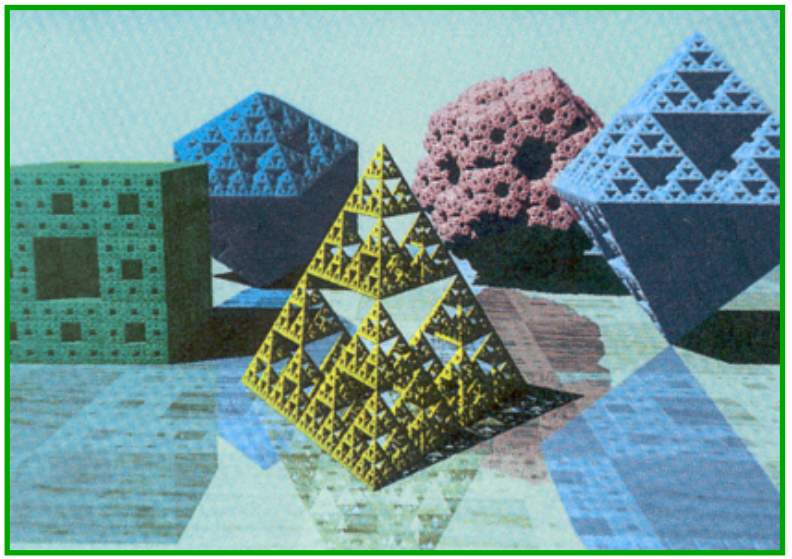
- Useful for creating interesting shapes!



Mandelbrot Figure 46

Deterministic Fractal Generation

- Useful for creating interesting shapes!



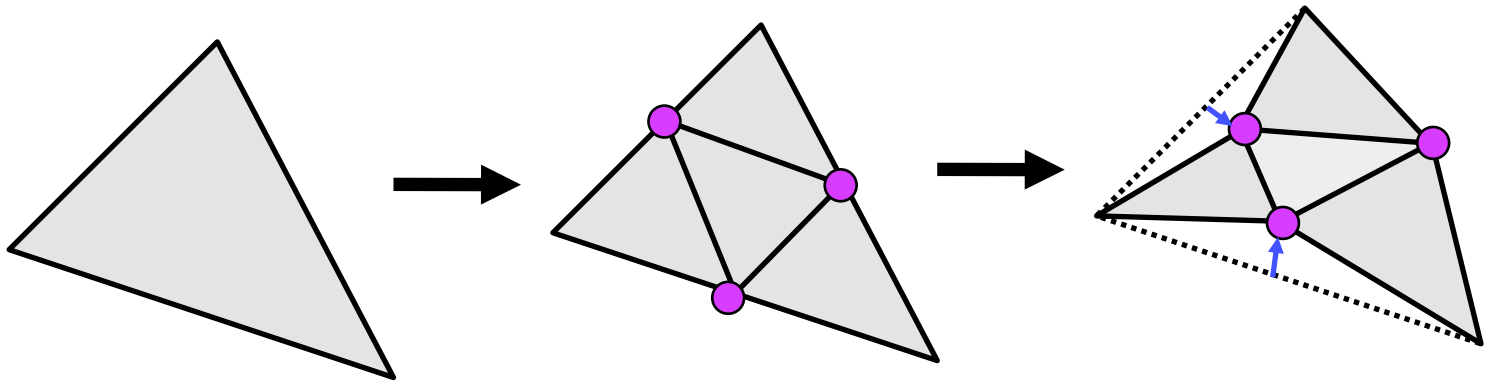
H&B Figures 75 & 109

Fractal Generation

- Deterministically self-similar fractals
  - Parts are scaled copies of original
- Statistically self-similar fractals
  - Parts have same statistical properties as original

Statistical Fractal Generation

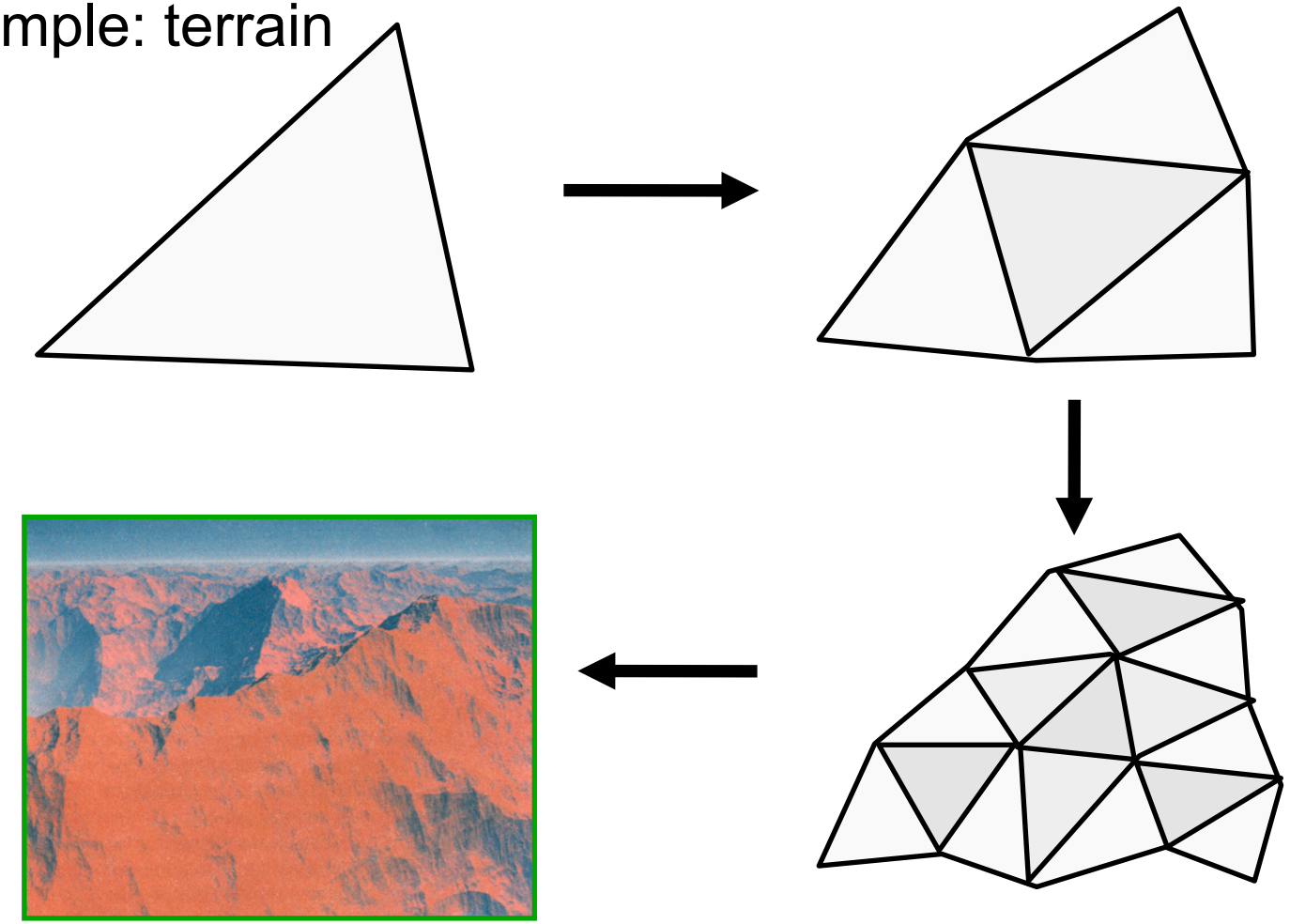
- General procedure:
  - Initiator: start with a shape
  - Generator: replace subparts with a self-similar random pattern



Random Midpoint Displacement

Statistical Fractal Generation

- Example: terrain



H&B Figure 10.83b

Statistical Fractal Generation

- Useful for creating mountains

H&B Figure 10.83a

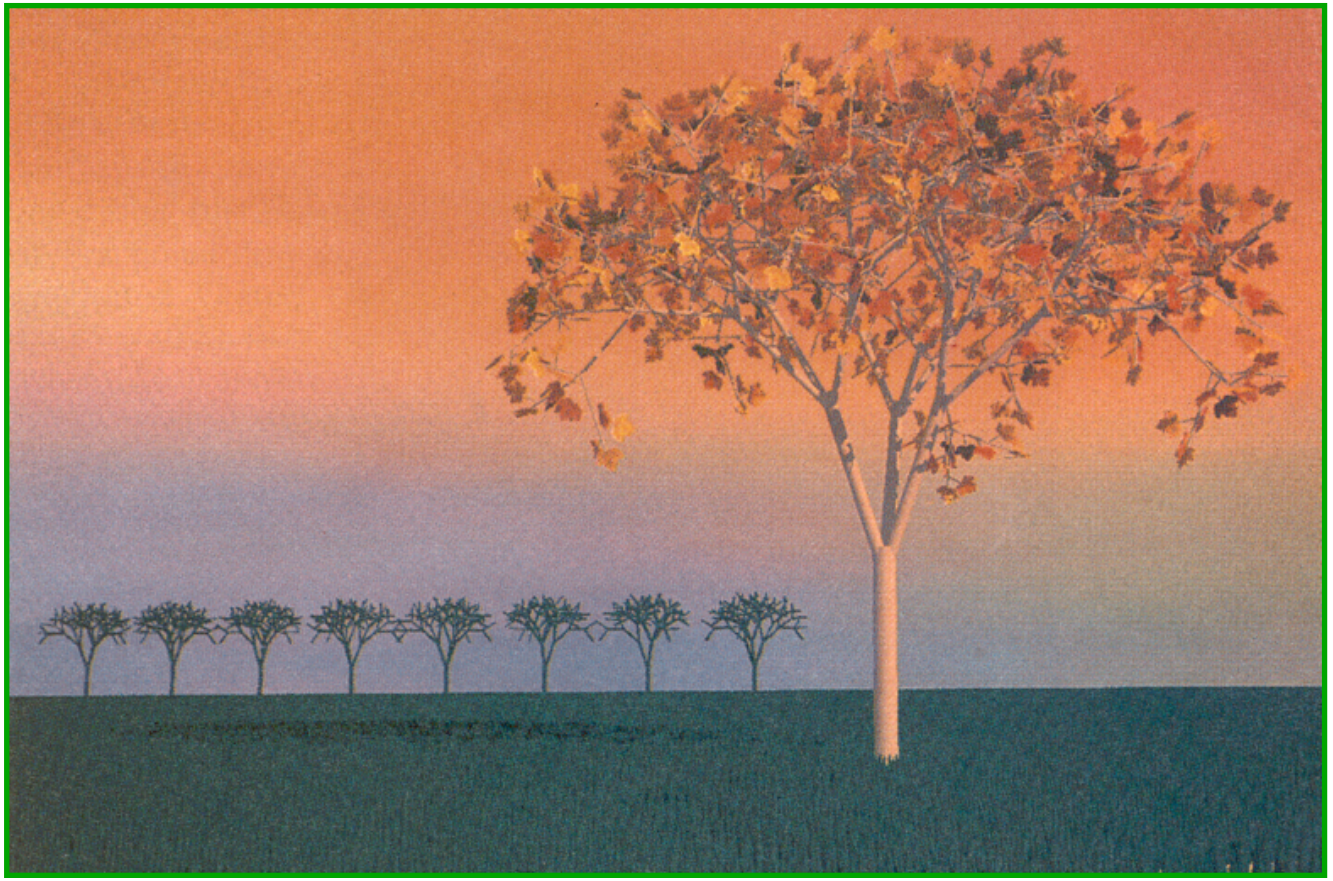
Statistical Fractal Generation

- Useful for creating 3D plants

H&B Figure 10.82

Statistical Fractal Generation

- Useful for creating 3D plants



H&B Figure 10.79

L-Systems

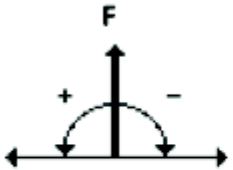
- Developed by **Aristid Lindenmayer** to model the development of plants
- Based on **parallel string-rewriting** rules
- Excellent for modeling organic objects and fractals

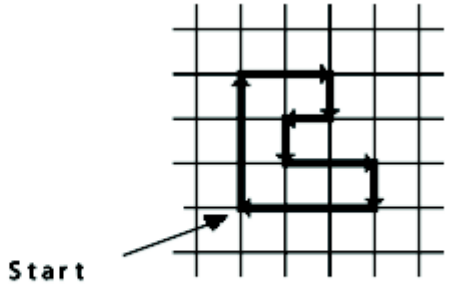
L-Systems Grammar

- Begin with a set of “productions” (replacement rules) and a “seed” axiom
- In parallel, all matching productions are replaced with their right-hand sides
- Ex:
  - Rules:
    - B → ACA
    - A → B
  - Axiom: AA
  - Sequence: AA, BB, ACAACA, BCBBCB, etc.
- Strings are converted to graphic representations via interpretation as turtle graphics commands

Turtle Commands

- F_x: move forward one step, drawing a line
- f_x: move forward one step, without drawing a line
- $+_x$: turn left by angle ∂
- $-_x$: turn right by angle ∂

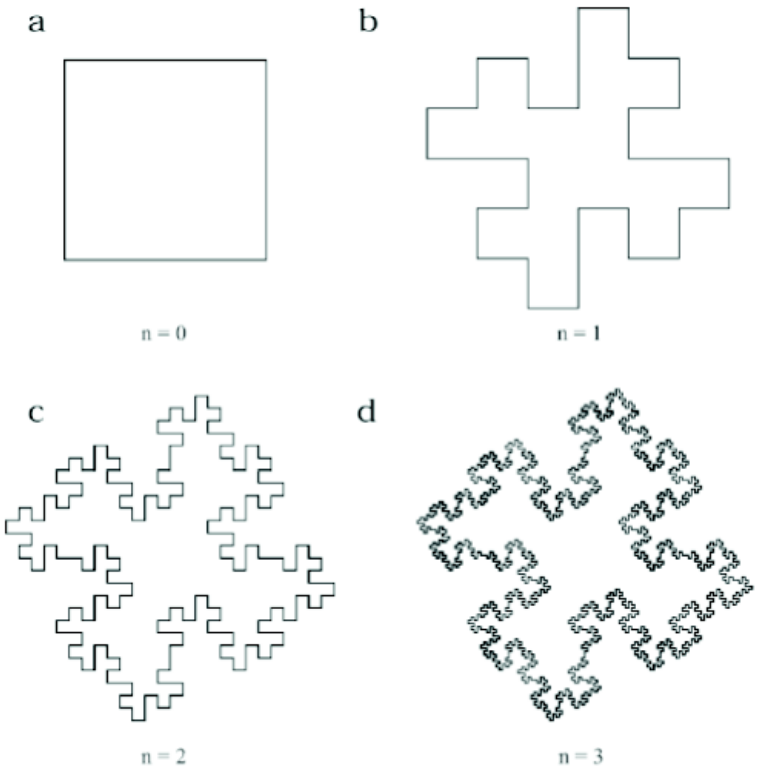




FFF-FF-F-F+F+FF-F-FFF

L-Systems Example: Koch Snowflake

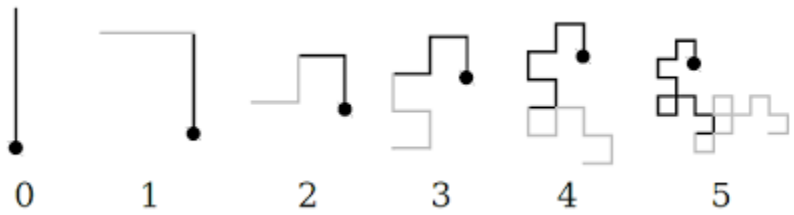
- Axiom: F-F-F-F ∂ :90 degrees
- F → F-F+F+FF-F-F+F

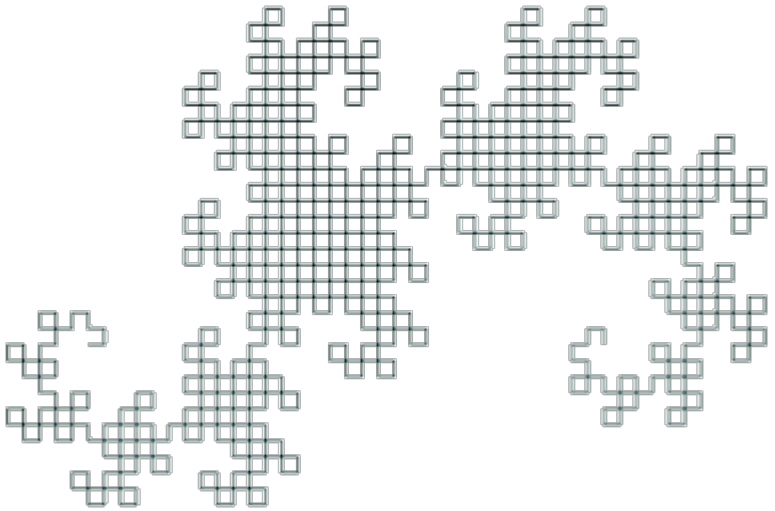


L-Systems Example: Dragon Curve

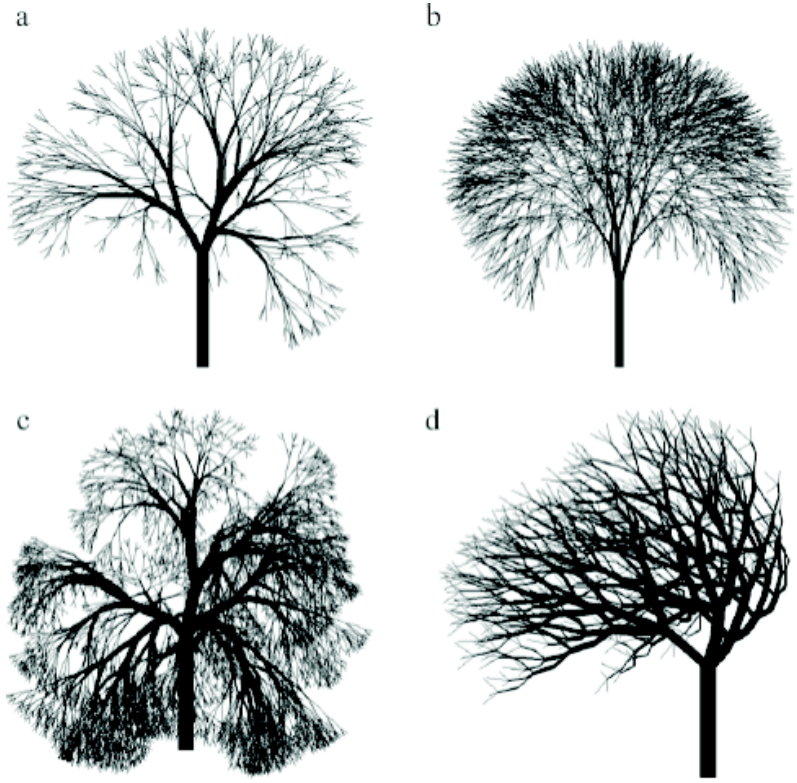
- A dragon curve is a recursive **nonintersecting** curve whose name derives from its resemblance to a certain mythical creature.

- Axiom: F_l ∂ :90 degrees n:10 iterations
- $F_l \rightarrow F_l+F_r+$
- $F_r \rightarrow F_l-F_r-$





L-Systems for Plants

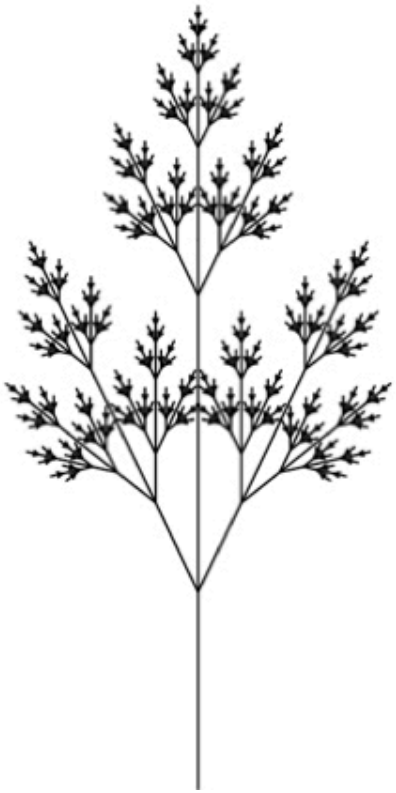


- L-Systems can capture a large array of plant species
- Designing rules for a specific species can be challenging

L-system

- alphabet: {a,b}
- initiator: a
- production rules:
  - a → b
  - b → ba
- generations:
  - a
  - b
  - ba
  - bab
  - babba
  - babbabab
  - babbababbabba
  - babbababbabbababbabab

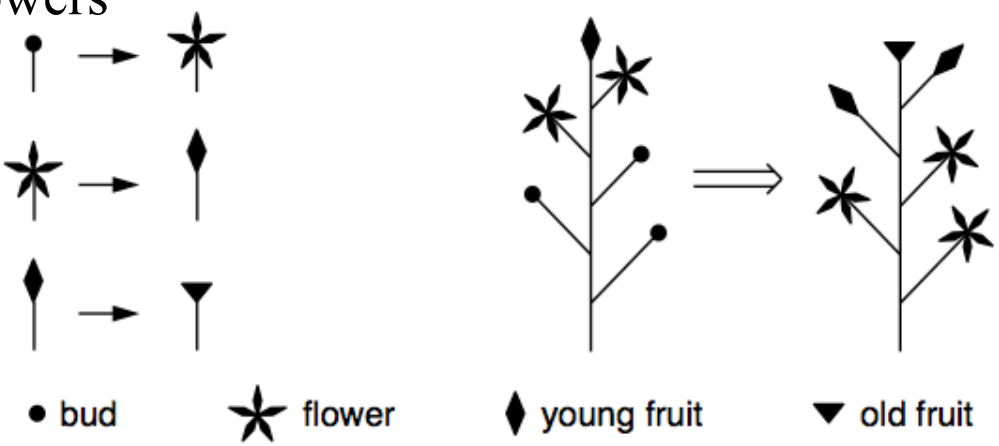
d
n=7 , δ=20°
X
X →F[+X]F[-X]+X
F →FF



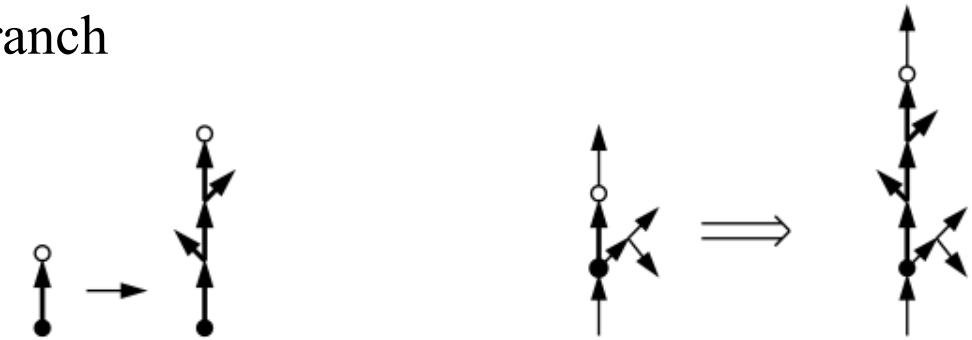
e
n=7 , δ=25.7°
X
X→F[+X][-X]FX
F→FF

L-system

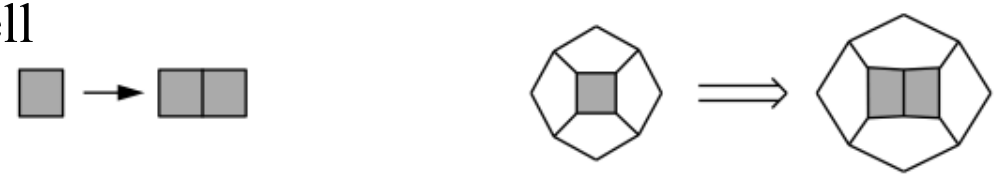
a) flowers



b) branch



c) cell



L-Systems

- Generation of plants
  Prusinkiewicz, Lindenmayer; 1990
- Environment-sensitive Prusinkiewicz, James, Mech; 1994
- Interaction (Open L-System)
  Mech, Prusinkiewicz; 1996
- Ecosystems
  Deussen, et al.; 1998




L-Systems Grammar: Extensions

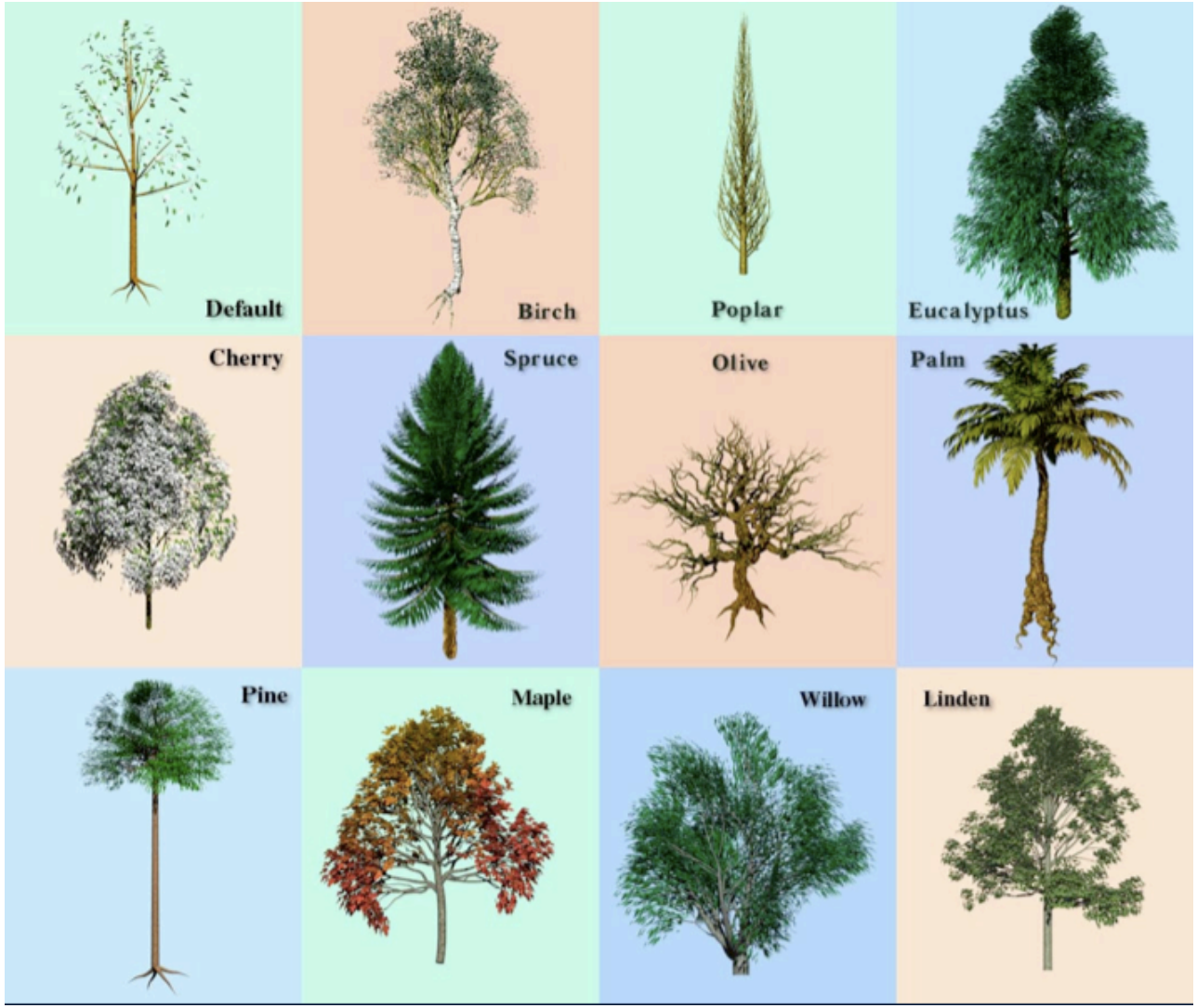
- Basic L-Systems have inspired a large number of variations
  - **Context sensitive**: productions look at neighboring symbols
  - **Bracketed**: save/restore state (for branches)
  - **Stochastic**: choose one of n matching productions randomly
  - **Parametric**: variables can be passed between productions

L-Systems: Further Readings

- Algorithmic Botany
  - Covers many variants of L-Systems, formal derivations, and exhaustive coverage of different plant types.
  - http://algorithmicbotany.org/papers
- PovTree
  - http://propro.ru/go/Wshop/povtree/povtree.html
  - http://arbaro.sourceforge.net/

http://arbaro.sourceforge.net/

PovTree

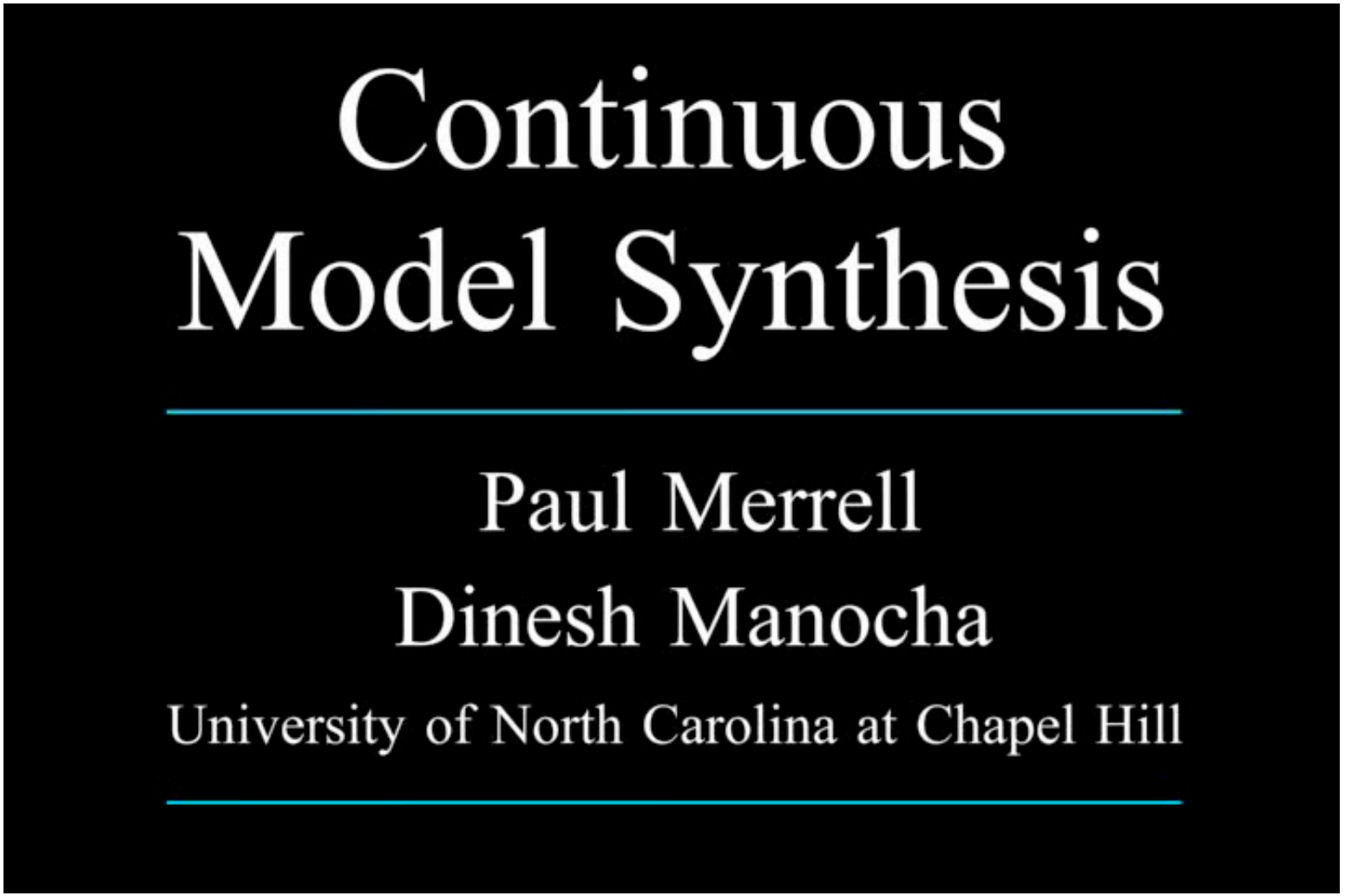

Default
Birch
Poplar
Eucalyptus
Cherry
Spruce
Olive
Palm
Pine
Maple
Willow
Linden

L-Systems for Cities/Game Levels

- Start with a single street
- Branch & extend w/ parametric L-System
- Parameters of the string are tweaked by goals/constraints
- Goals control street direction, spacing
- Constraints allow for parks, bridges, road loops
- Once we have streets, we can form buildings with another L-System
- Building shapes are represented as CSG operations on simple shapes

Procedural Modeling of Buildings

Example-Based Approach

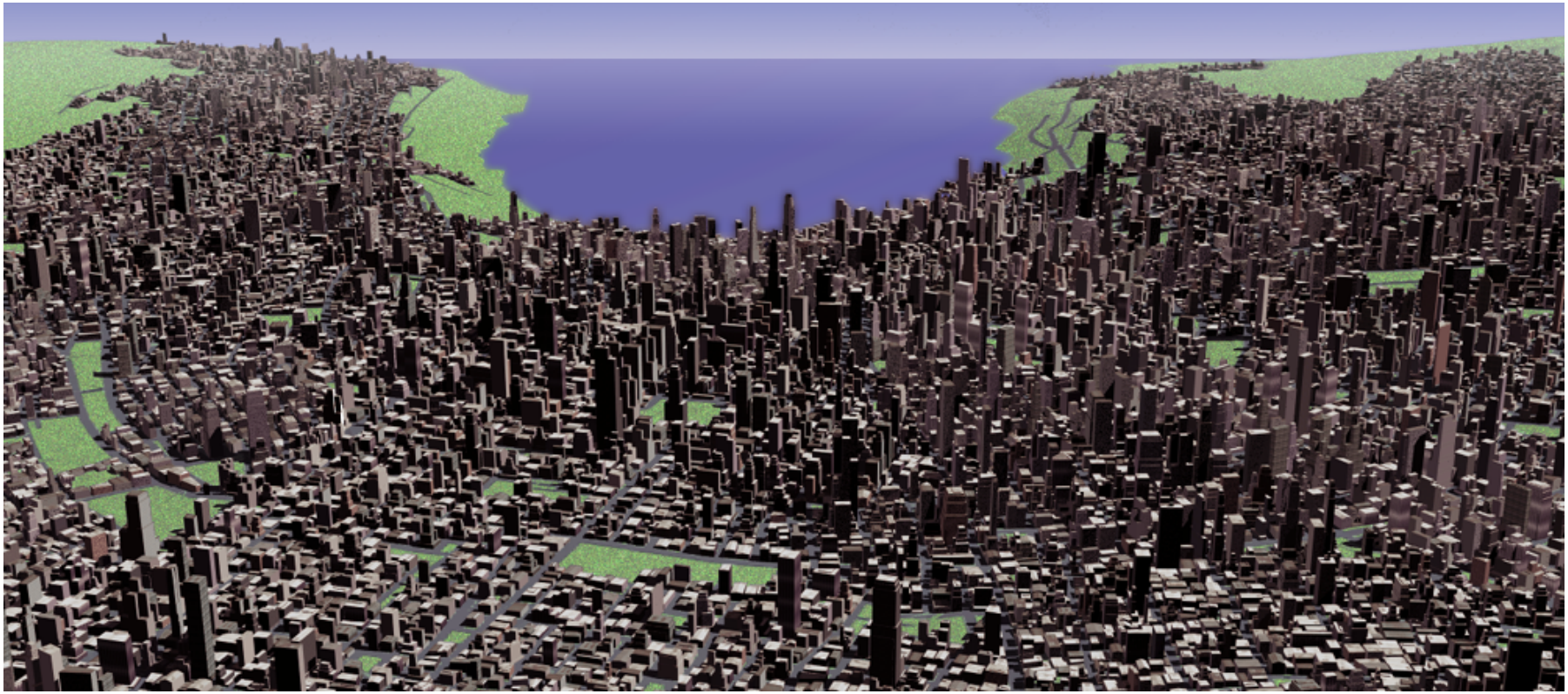


The City Engine System

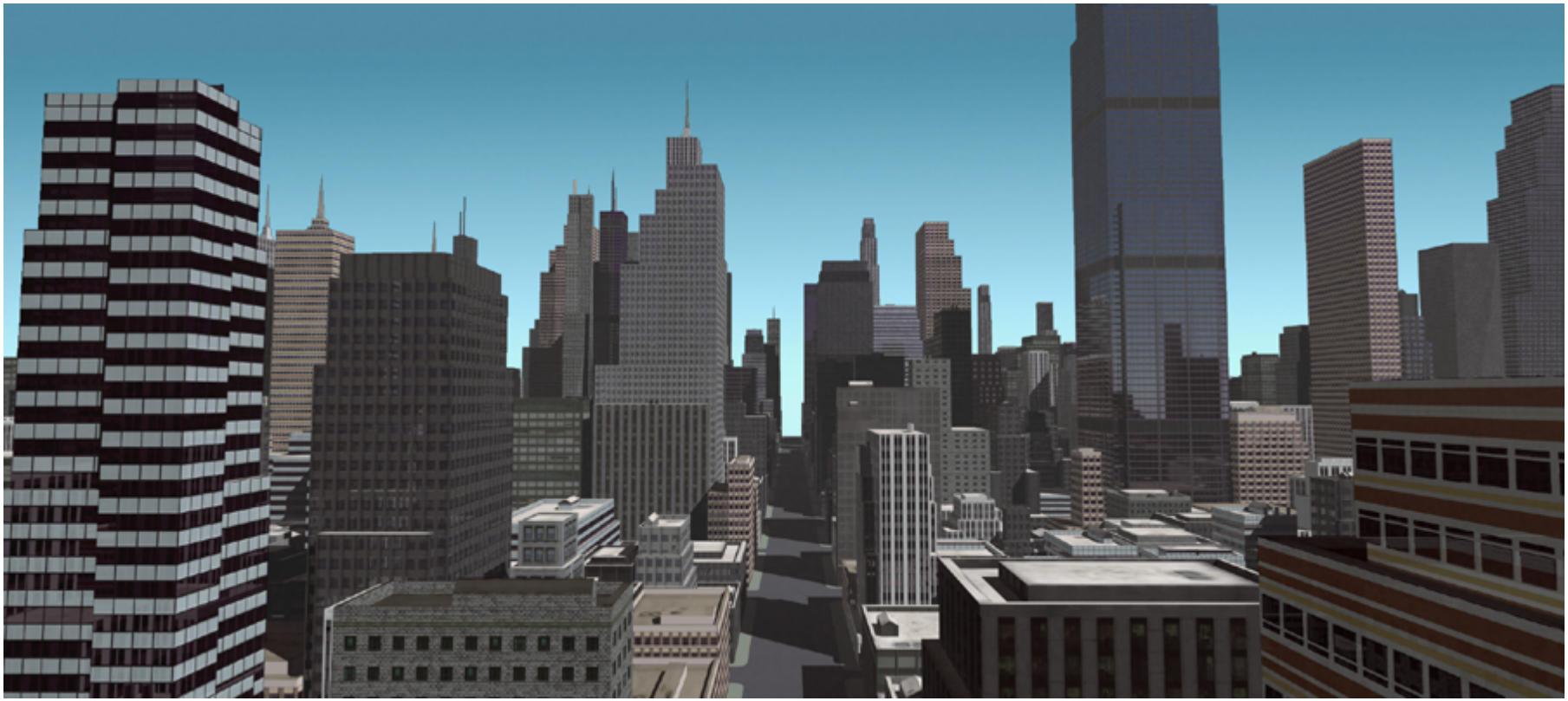
- Procedurally creates complex city models.

- Cities consist of:
  - Street maps
  - Buildings
  - Facade textures

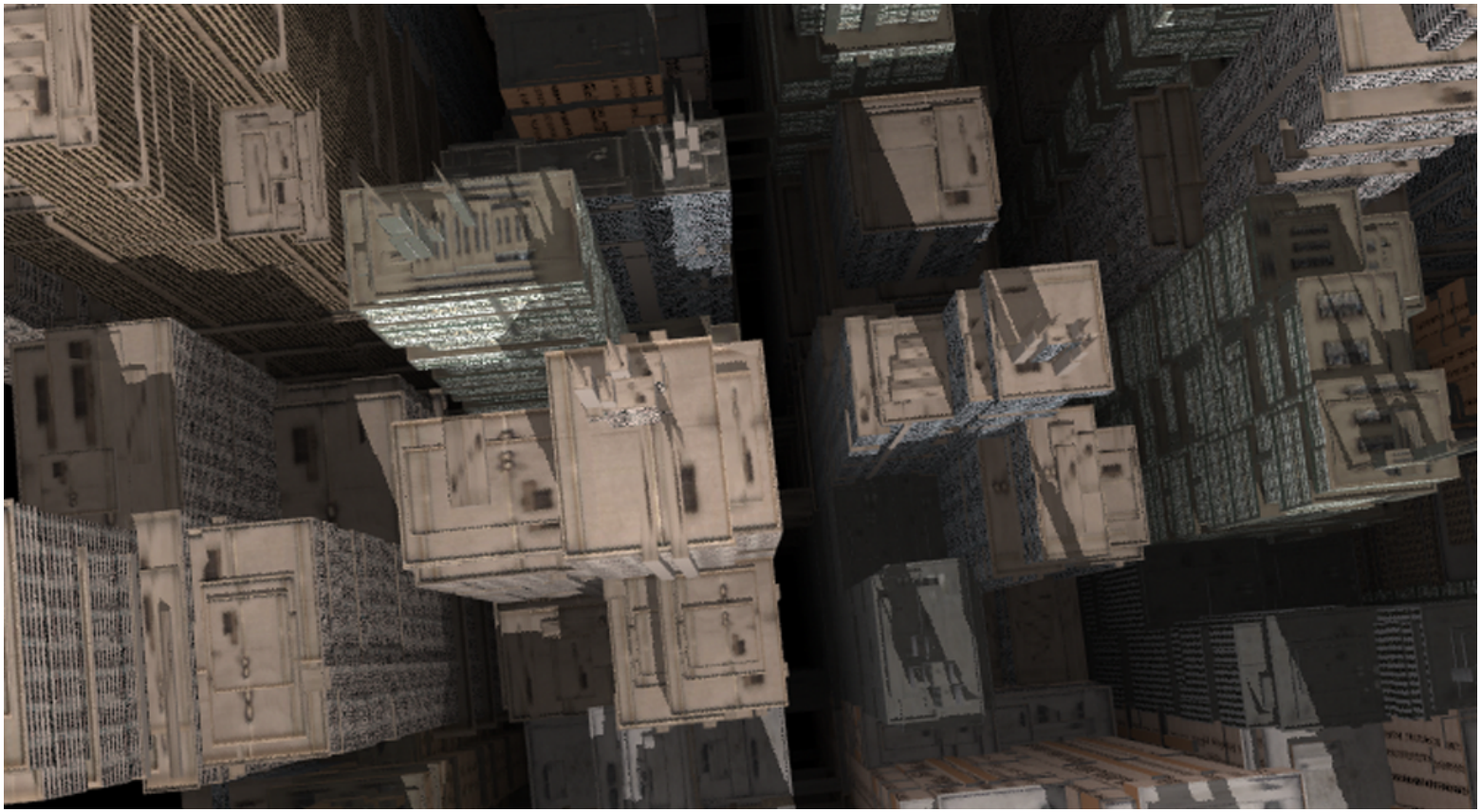
Example Zurich-London-Paris



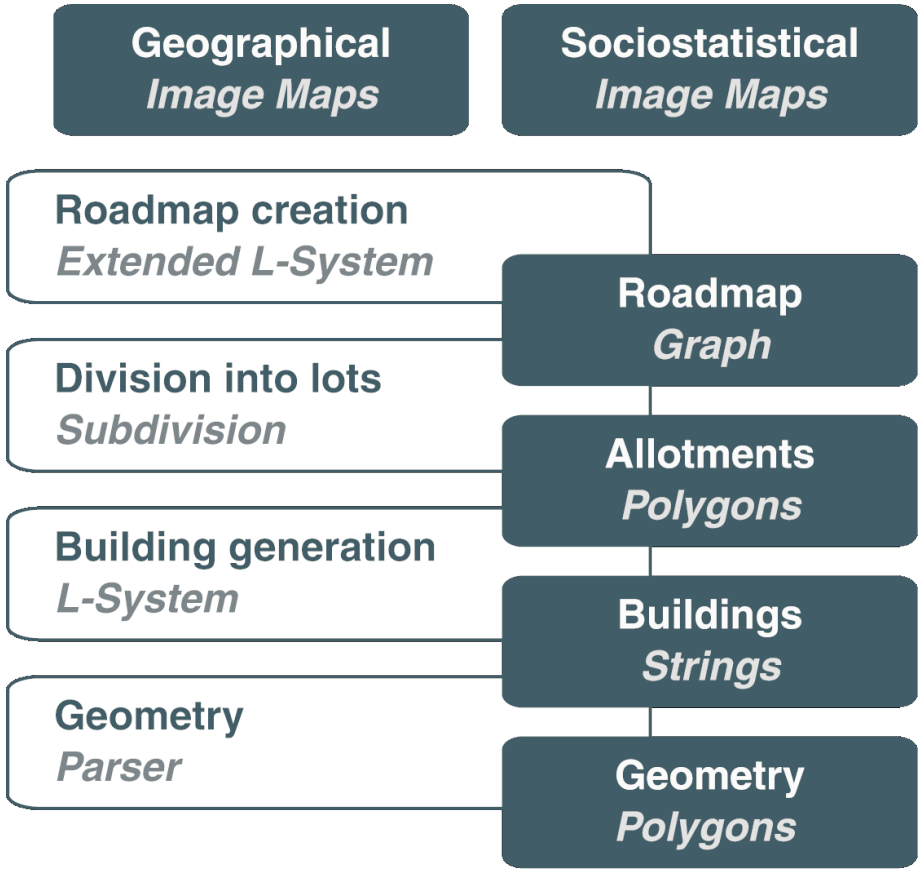
Example Manhattan



Example Manhattan 2259

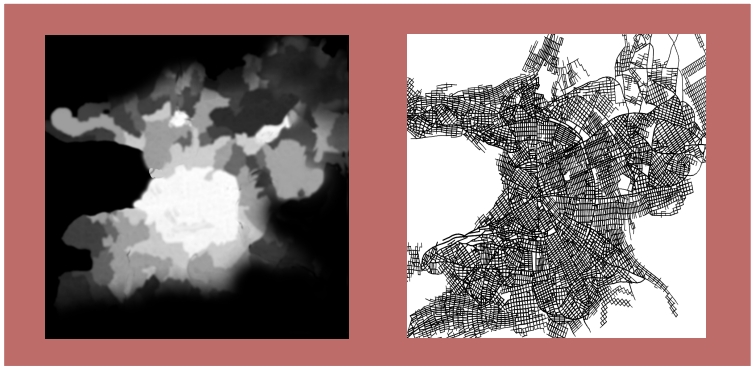


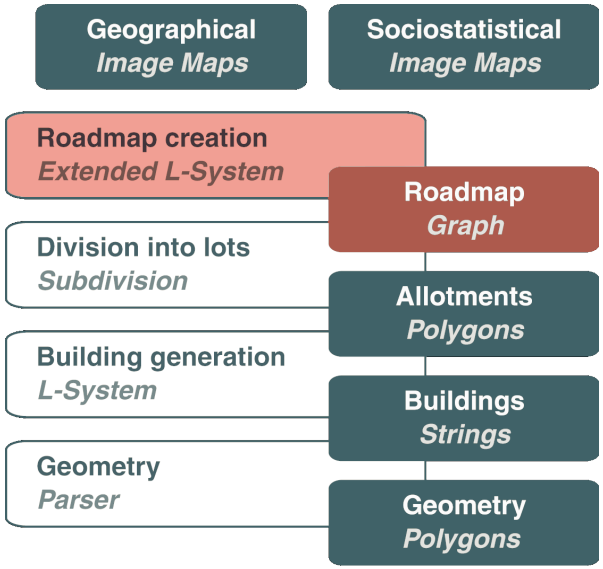
System Pipeline



Module 1: Streetmap Creation

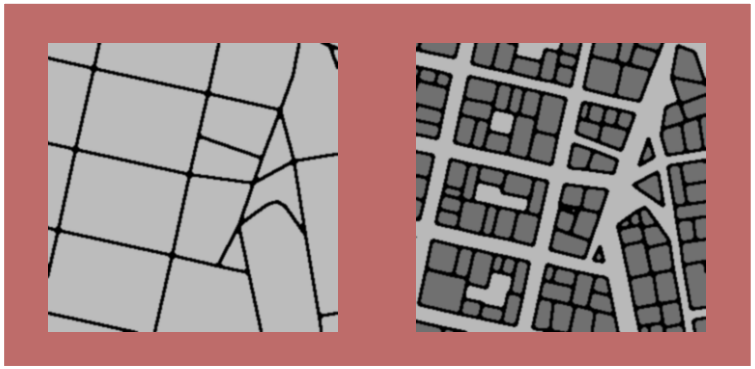
- Input:
  Image maps, parameters for rules
- Output:
  A street graph for interactive editing

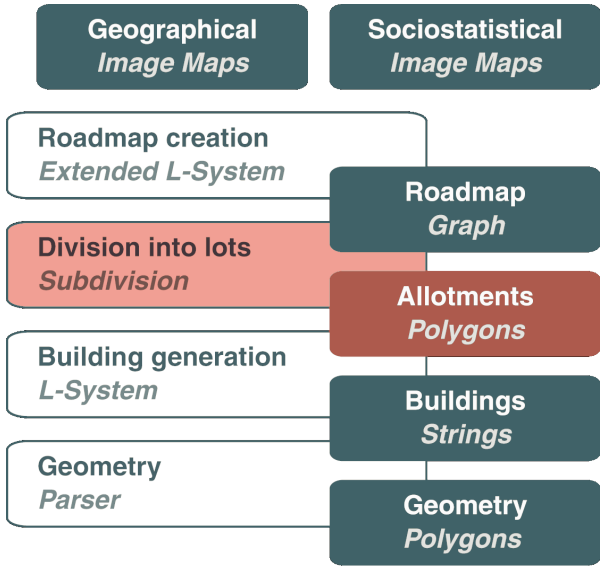




Module 2: Division into Lots

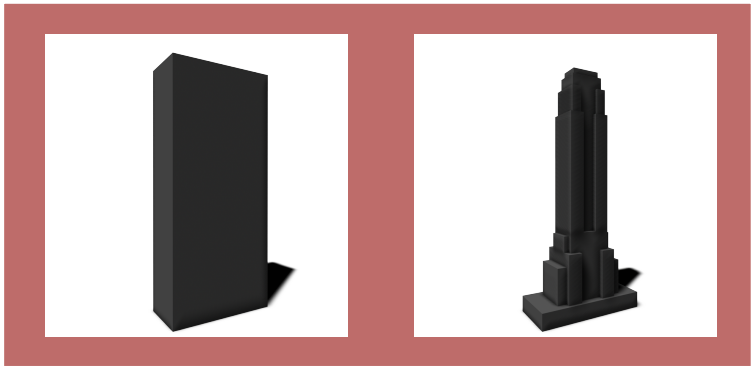
- Input:
  Street graph, area usage map
- Output:
  Polygon set of allotments for buildings

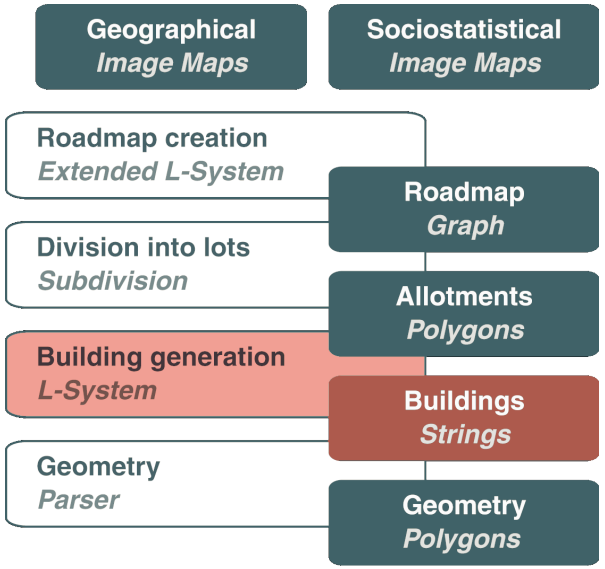




Module 3: Building Generation

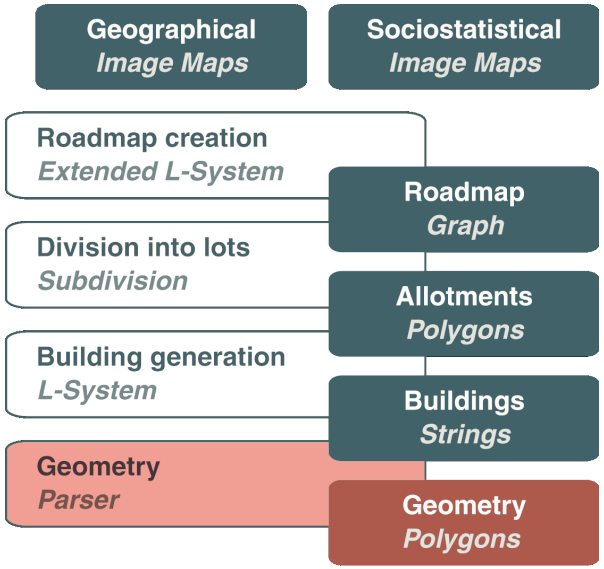
- Input:
  Lot polygons, age map and zone plan
- Output:
  Building strings with additional info

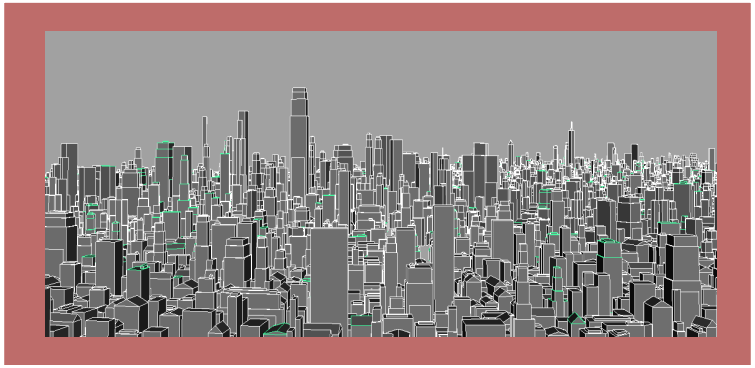




Module 4: Geometry and Facades

- Input:
  Strings and building type
- Output:
  City geometry and facade texture (procedural shader)





L-Systems for Streets

- Grouping parameters of different street patterns
- Hierarchical influences: global goals and local constraints

Extended L-Systems

- Template successor defines 3 branches
- Parameters fields are unassigned

Extended L-Systems

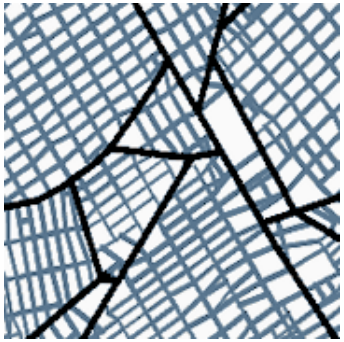
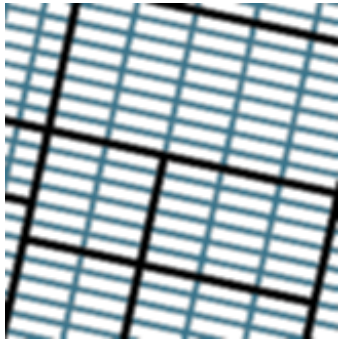
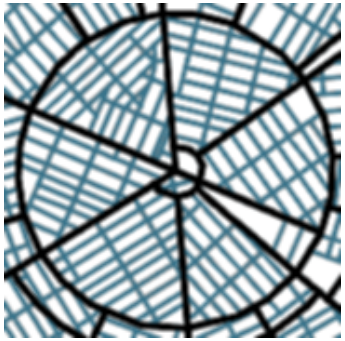
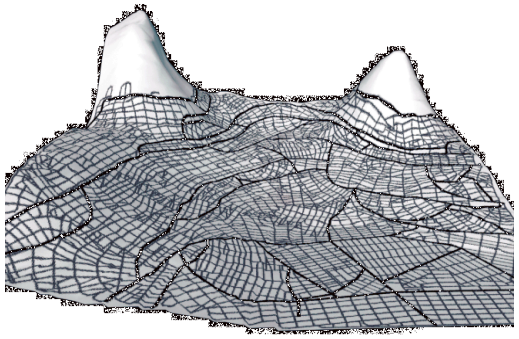
- Initial parameter settings
- Design goal

Extended L-Systems

- Parameter value correction
- Influenced by local environment

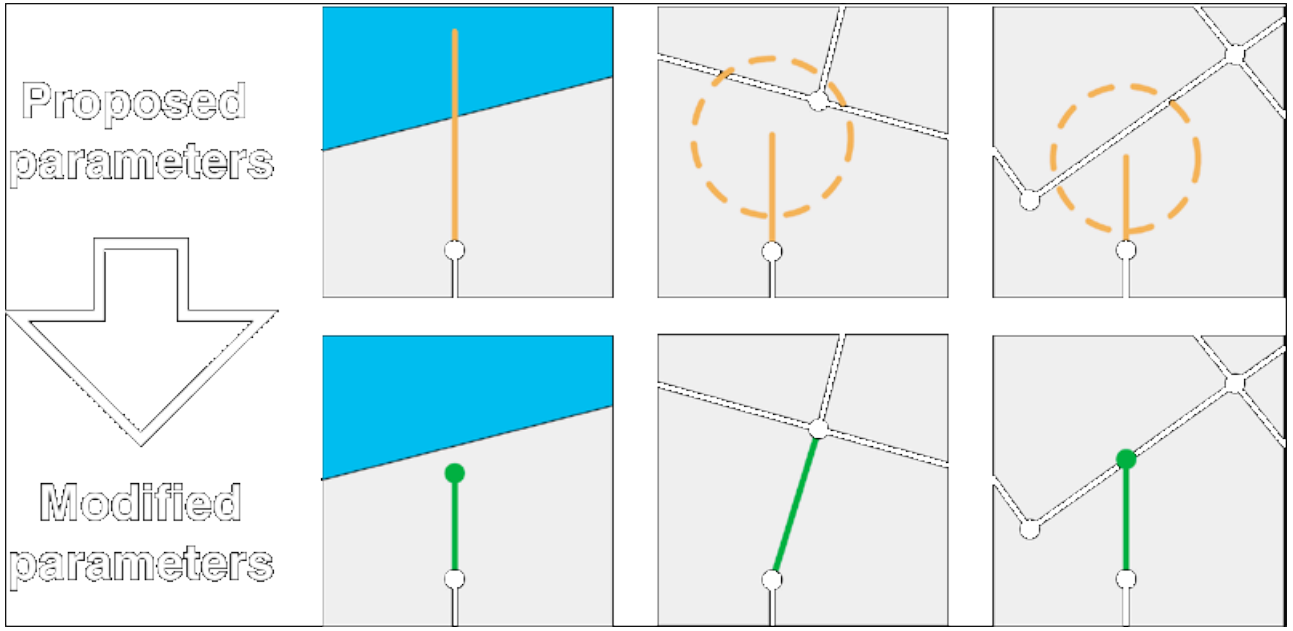
Global Goals

- Could be a planned urban design
- Different goals in the same city
- Controlled by image map (user input)

Local Constraints

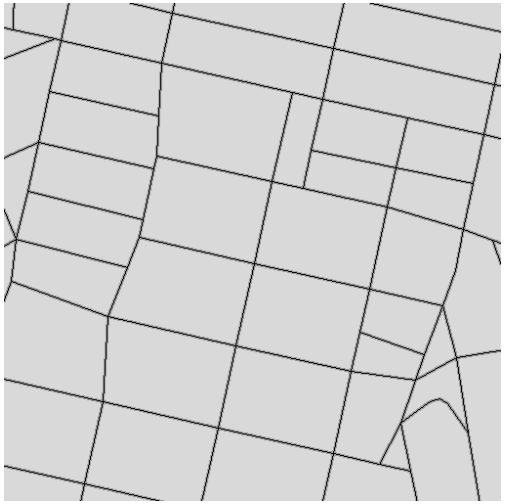
- Environment-sensitivity for legal streets
- Self-sensitivity for closed loops

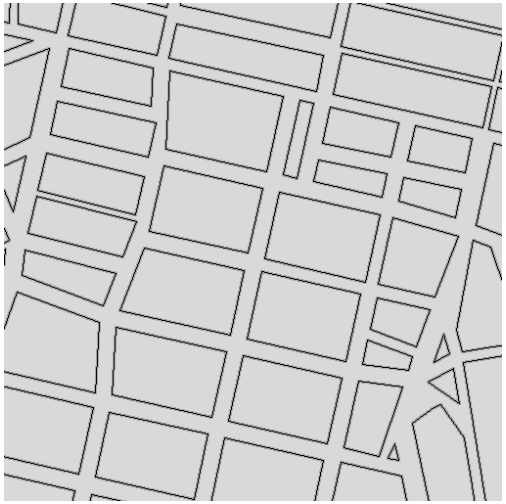


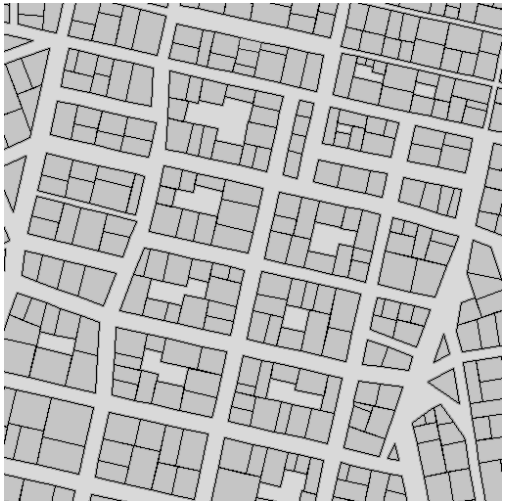
Division into Lots

- Lot area depends on:
- Land Use map
- Population density

- **Building height**
- **Access to street**

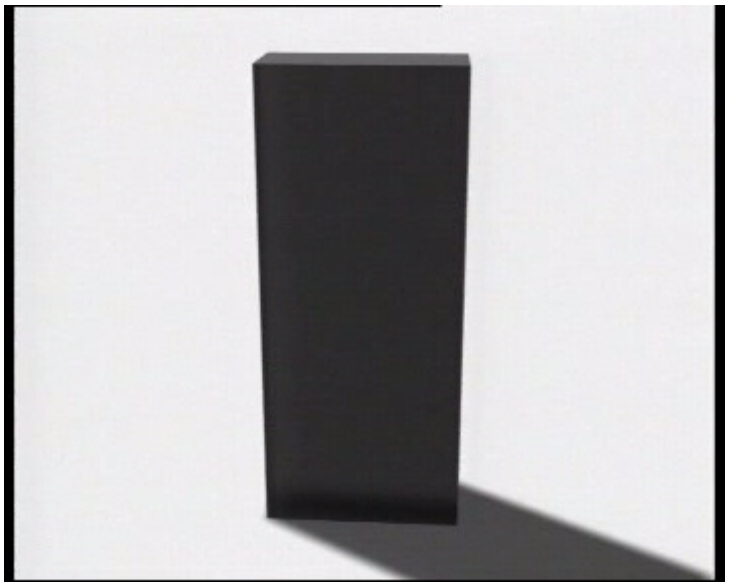






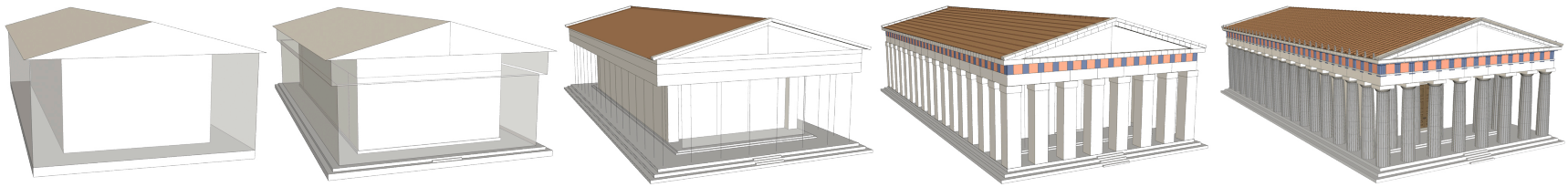
Procedural Buildings

- Modeled with a common L-System
- L-System modules consist of geometric operations like extrusion



CGA Shape

- Production process:
- Rule-driven modification & replacement of shapes
- Iteratively evolve a design by creating more and more details
- Sequential application (like Chomsky grammars)

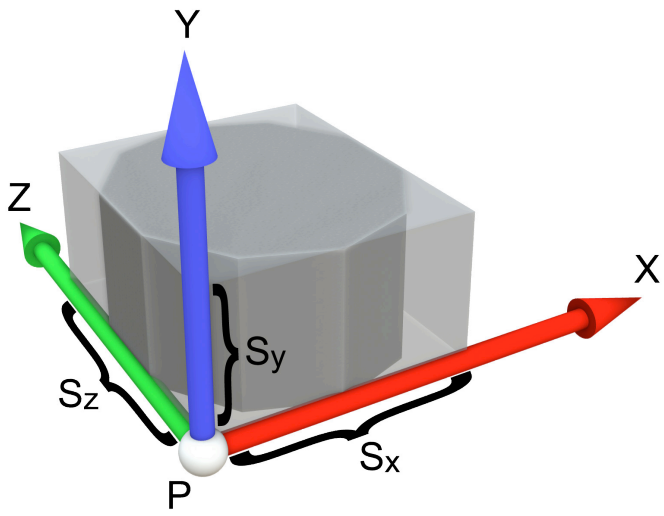


Shape Rules

- Notation:

id: predecessor : condition ⇢ successor : prob

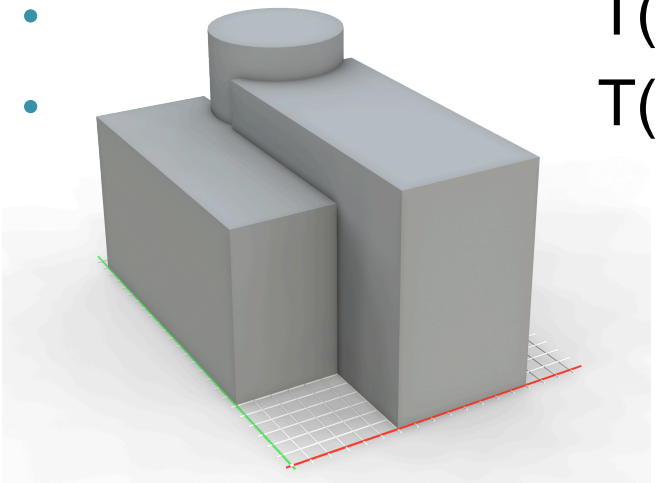
- A shape consists of:
  - Symbol (string)
  - Geometry (geometric attributes)
  - Oriented bounding box called scope (numeric attributes)



Basic Shape Operations

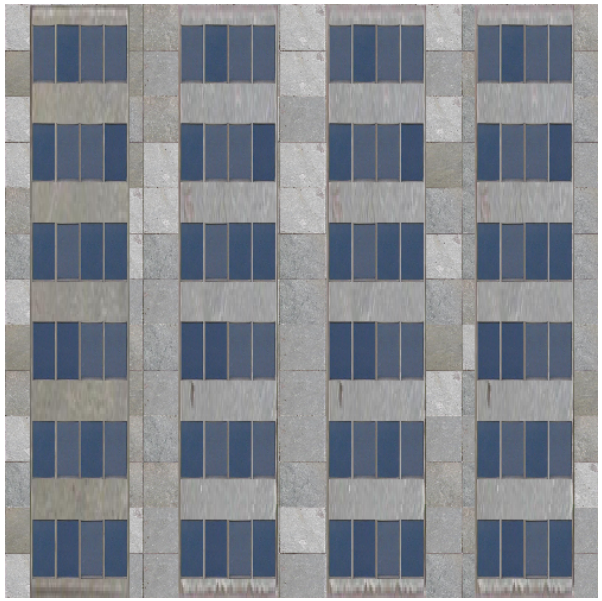
- Insertion: I(obj_Id)
- Transformations: T(tx,ty,tz), S(sx,sy,sz), Rx(α)..
- Branching: [...]

- Simple example:
- 1: A ⇢ [T(0,0,6) S(8,10,18) I(“cube”)]
- T(6,0,0) S(7,13,18) I(“cube”)
- T(0,0,16) S(8,15,8) I(“cylinder”)



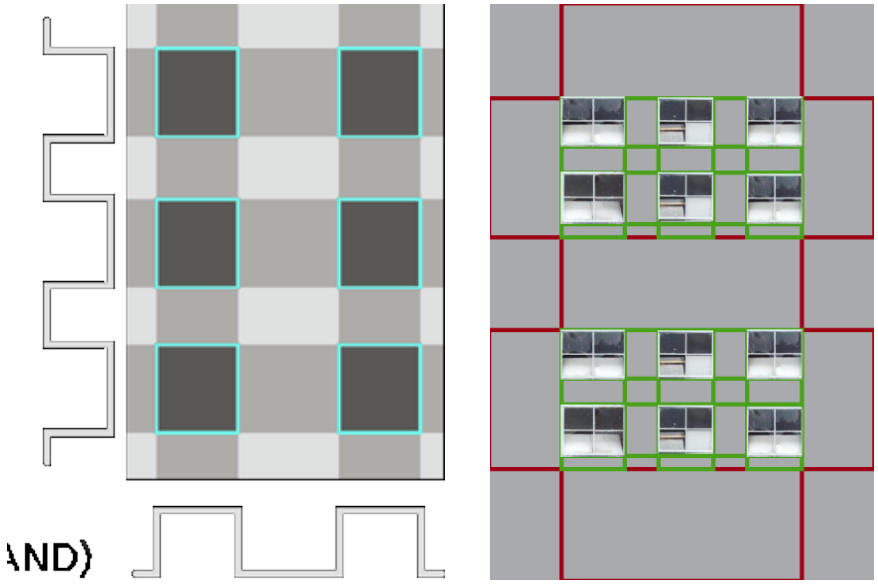
Facade Textures

- Division into simple grid-like structures
- Structures can be layered



Layered Textures

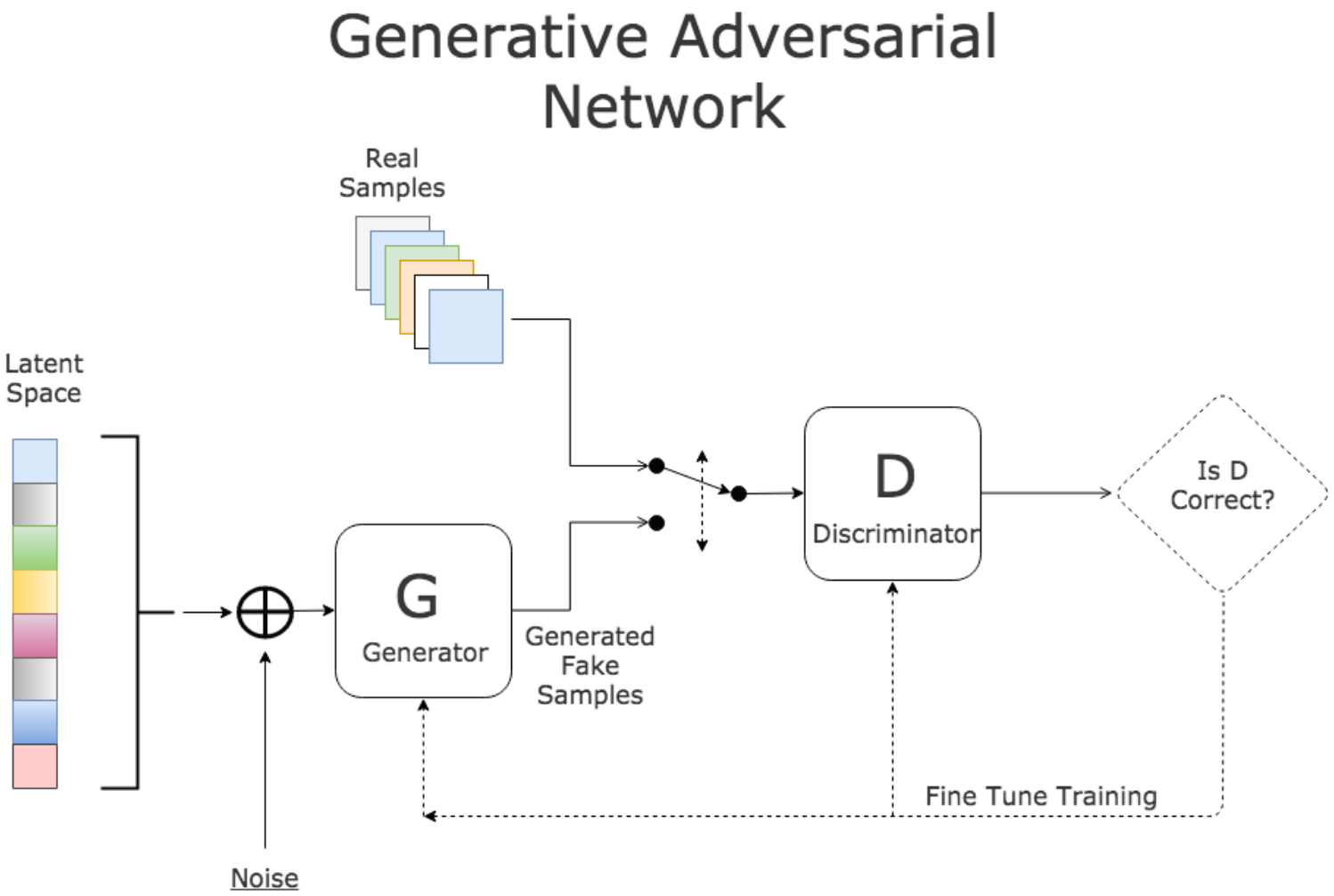
- Two base functions form a layer
- Every layer defines a facade element



Modeling and Synthesizing Sounds

- https://www.youtube.com/watch?v=RdoGlKOvzKk
- https://www.youtube.com/watch?v=PMSV7CjBuZI
- https://www.youtube.com/watch?v=7xzKyIq9h3s
- https://www.youtube.com/watch?v=5I8KCTuDBek

GAN: Generative Adversarial Network



GAN Examples

Pokemon: https://www.youtube.com/watch?v=yz6dNf7X7SA

3D Model: http://3dgan.csail.mit.edu/