Texture Representations

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Texture

- What is it?
  - Definitions not sharp
  - Image of stationary statistics
  - Pattern repeated in an image
  - Whenever I see “too many”
- Extreme variability
- People miss the means of describing them

Human description & comparison

Texture

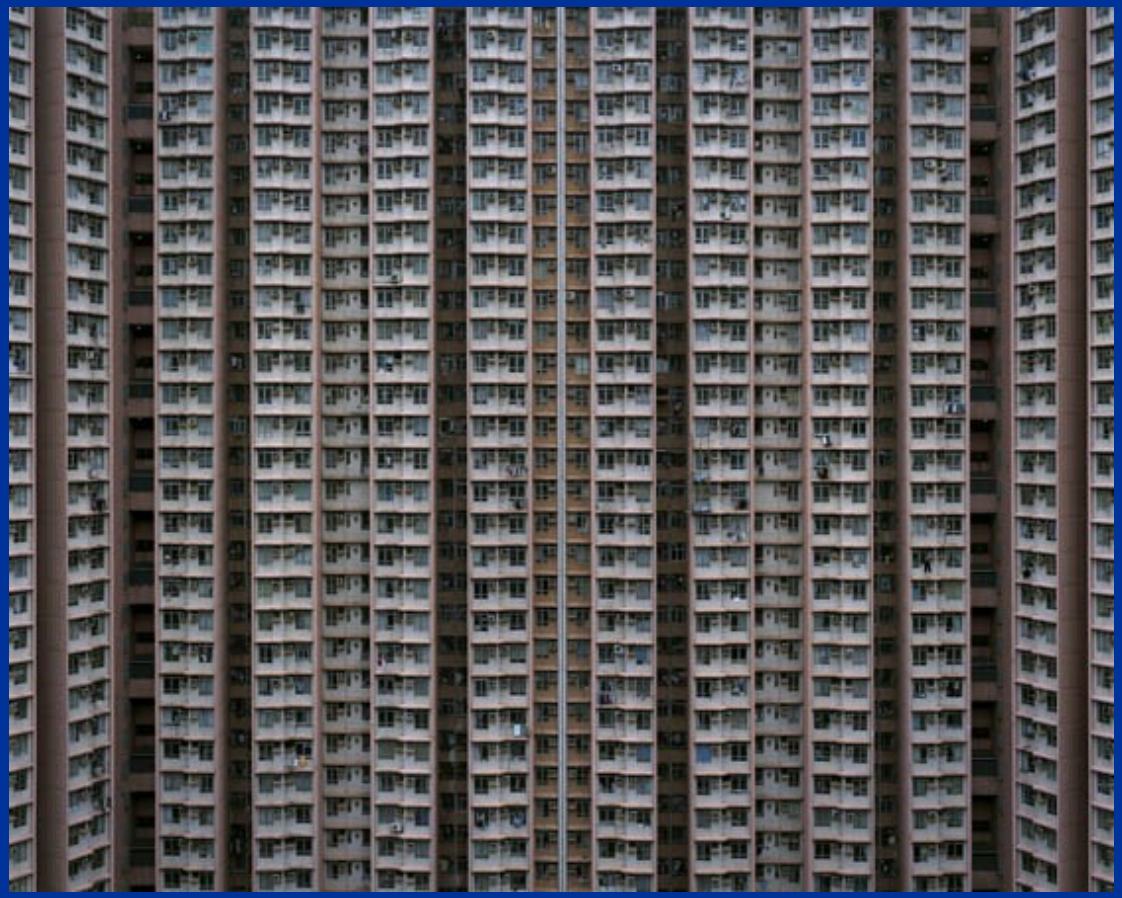
Regular & homogeneous

Texture

Stochastic

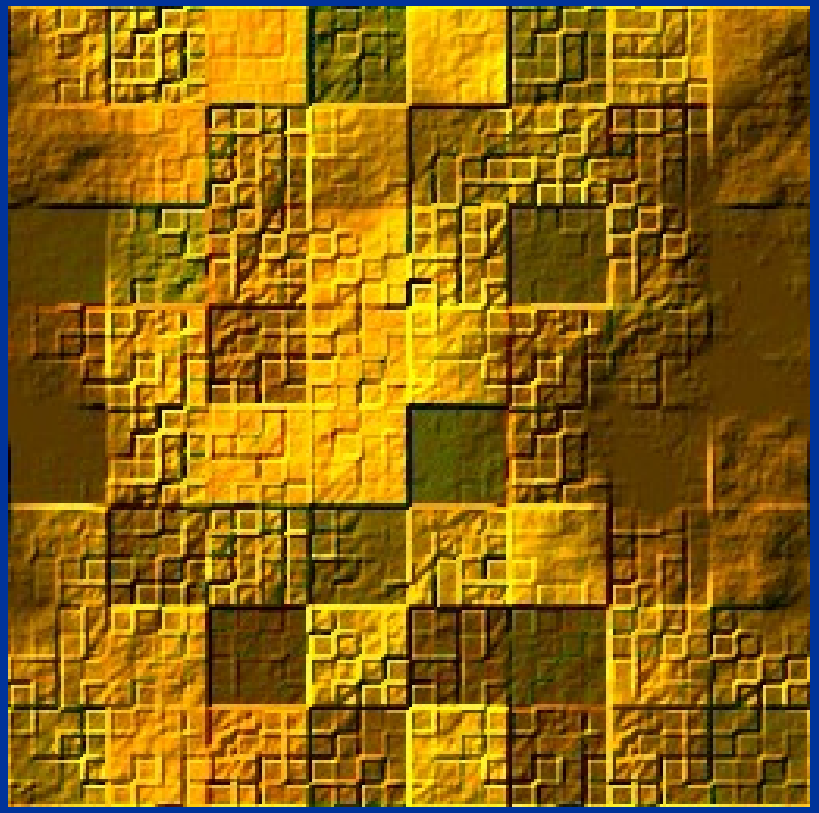
Texture

Slightly non-regular/non-homogeneous



Texture

Mild reflectance variations



Texture

Strong reflectance variations & warping

Texture

Stochastic scale variation

Texture

Stochastic scale, shape, reflectance variation

Texture and Structure: The matter of scale

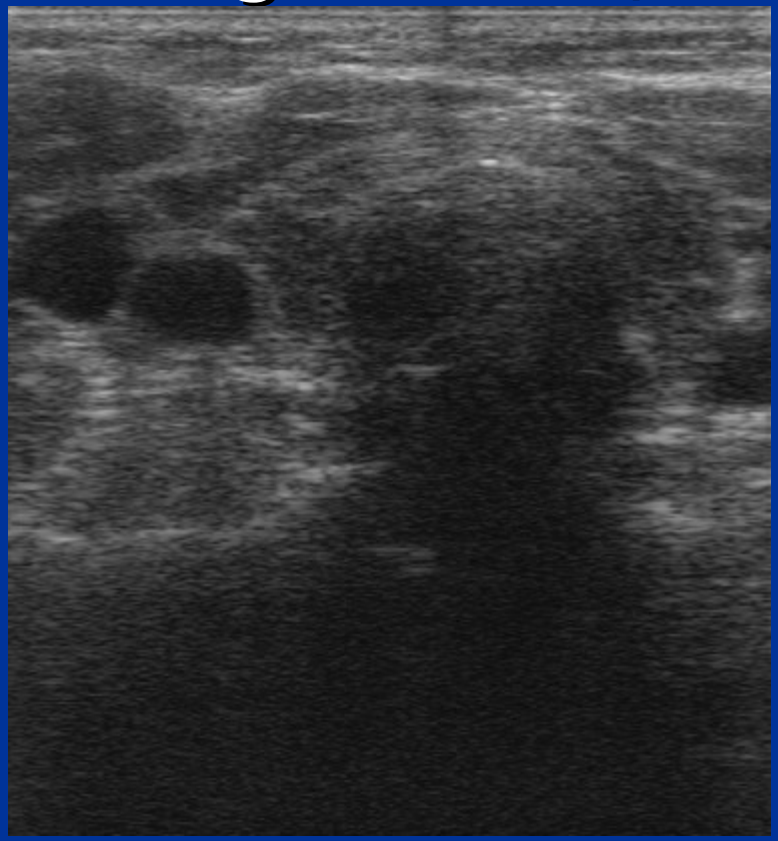
Motivation

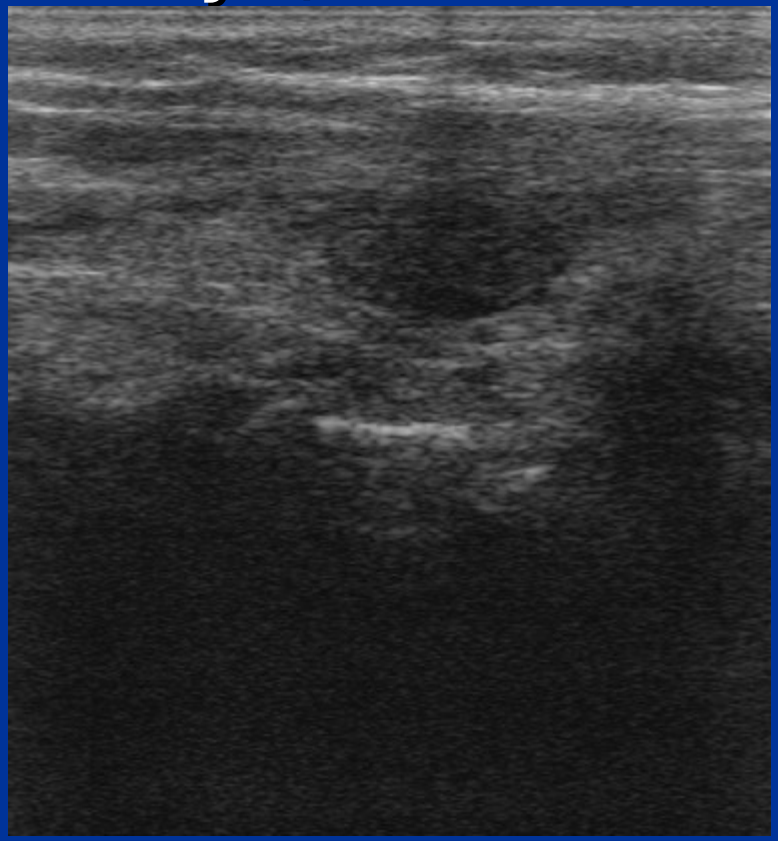
- assessment quality of ...
- ... food
- ... materials (think of interior of BMW)
- ... “healthiness”
- ...

Motivation

Motivation

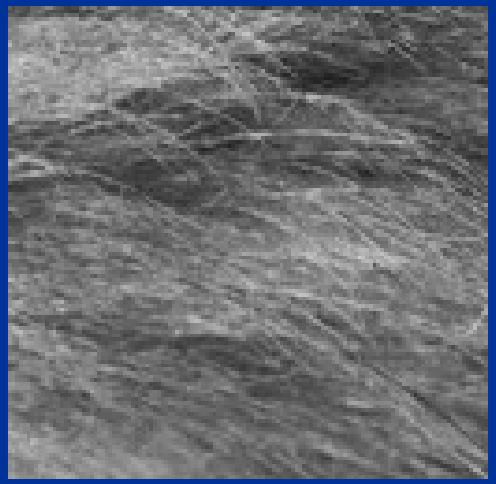
- atrophic thyroitidis
- diagnostics (heart, kidneys)

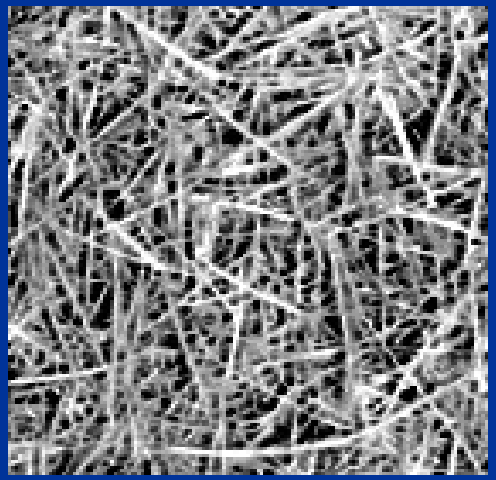




Description

- **primitives (texels)**
- spatial structure → statistical properties





Description

- primitives (texels)
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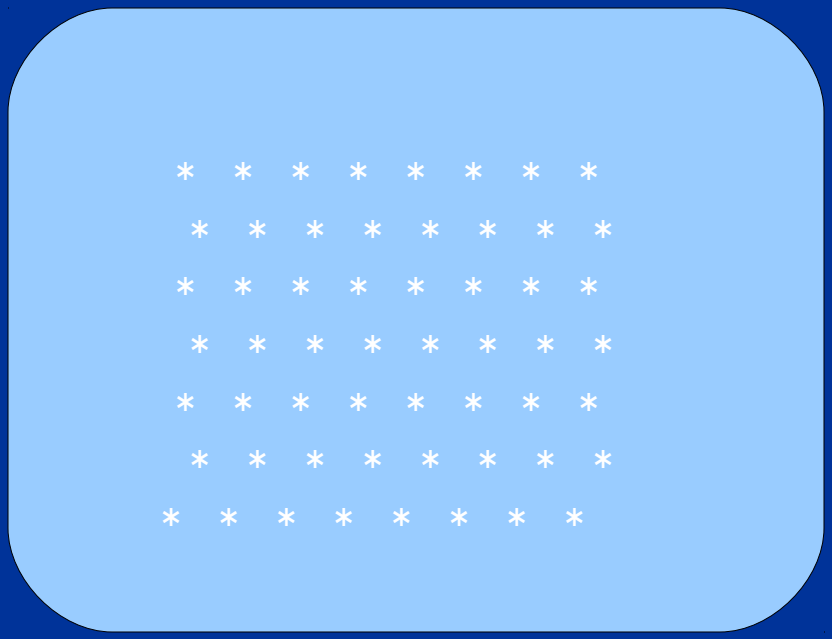
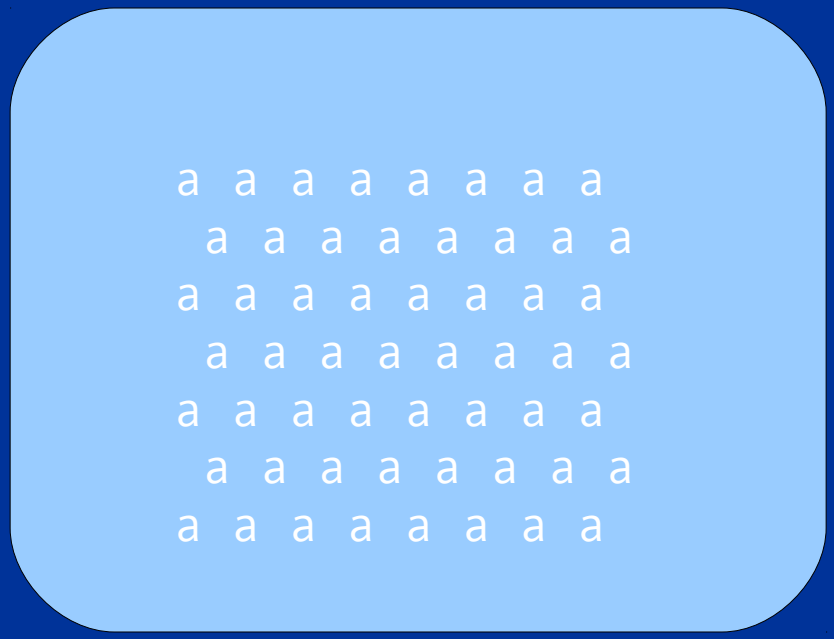




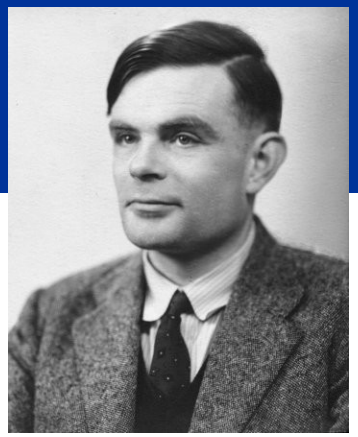
What’s texture? Forward problem

- In Nature, often fairly simple mechanisms
- Reaction-diffusion systems
- Bubbles
- Dead leaves
- Space filling

- (These subjects studied in the Computer Graphics community)

Reaction-Diffusion

- Reaction Diffusion (Turing, 1952) The Chemical Basis of Morphogenesis



THE CHEMICAL BASIS OF MORPHOGENESIS

By A. M. TURING, F.R.S. *University of Manchester*

(*Received* 9 *November* 1951—*Revised* 15 *March* 1952)

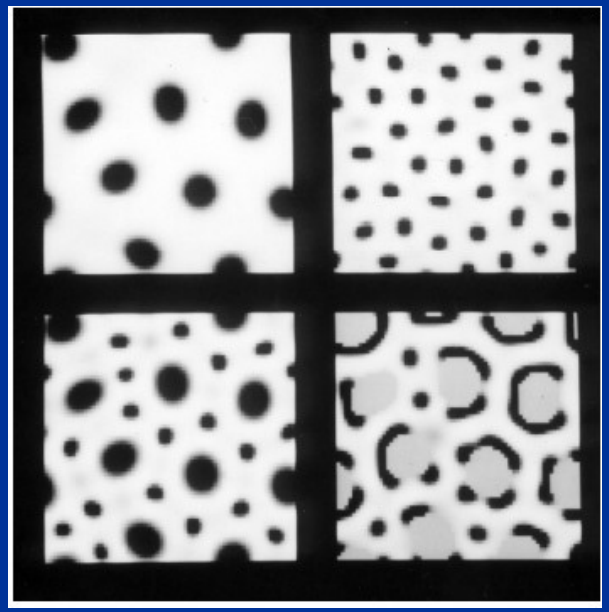
It is suggested that a system of chemical substances, called morphogens, reacting together and diffusing through a tissue, is adequate to account for the main phenomena of morphogenesis. Such a system, although it may originally be quite homogeneous, may later develop a pattern or structure due to an instability of the homogeneous equilibrium, which is triggered off by random disturbances. Such reaction-diffusion systems are considered in some detail in the case of an isolated ring of cells, a mathematically convenient, though biologically unusual system. The investigation is chiefly concerned with the onset of instability. It is found that there are six essentially different forms which this may take. In the most interesting form stationary waves appear on the ring. It is suggested that this might account, for instance, for the tentacle patterns on *Hydra* and for whorled leaves. A system of reactions and diffusion on a sphere is also con-

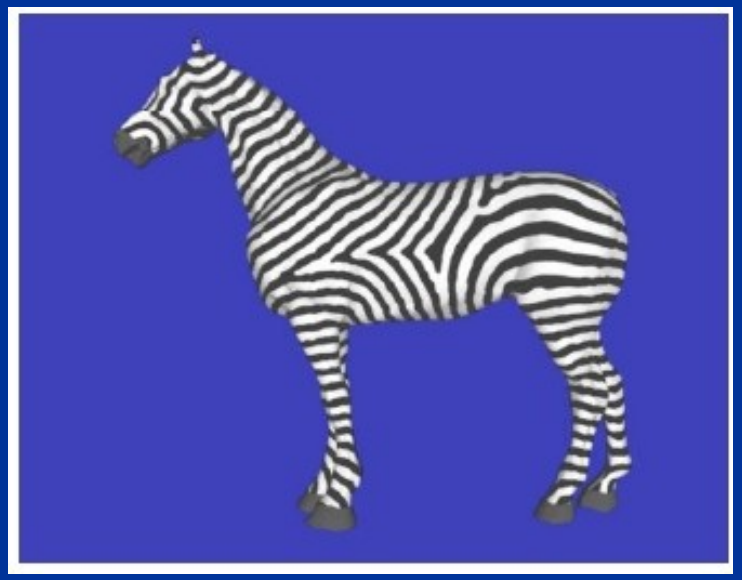
Reaction-Diffusion

- Reaction Diffusion (Turing, 1952) The Chemical Basis of Morphogenesis

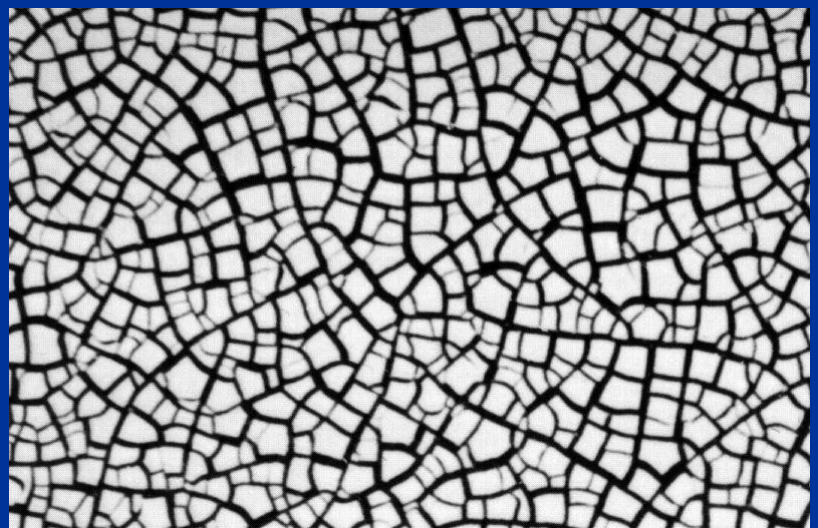
Reaction-Diffusion

- Greg Turk (SIGGRAPH 91)





Breaks

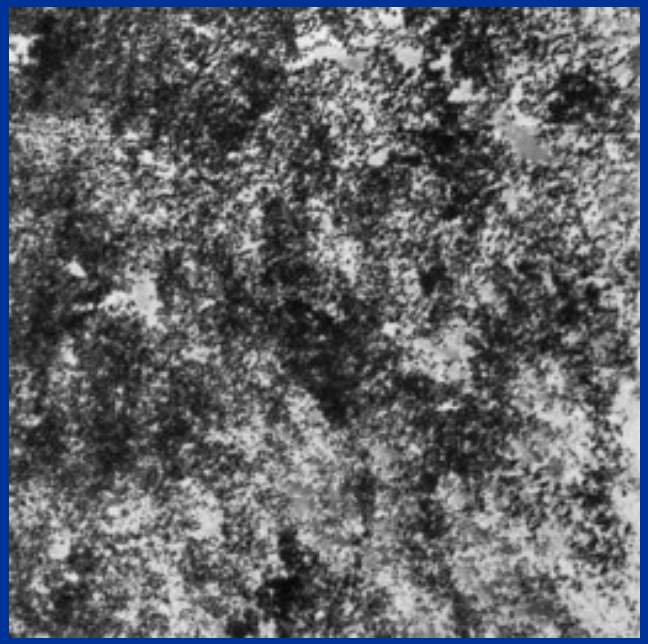


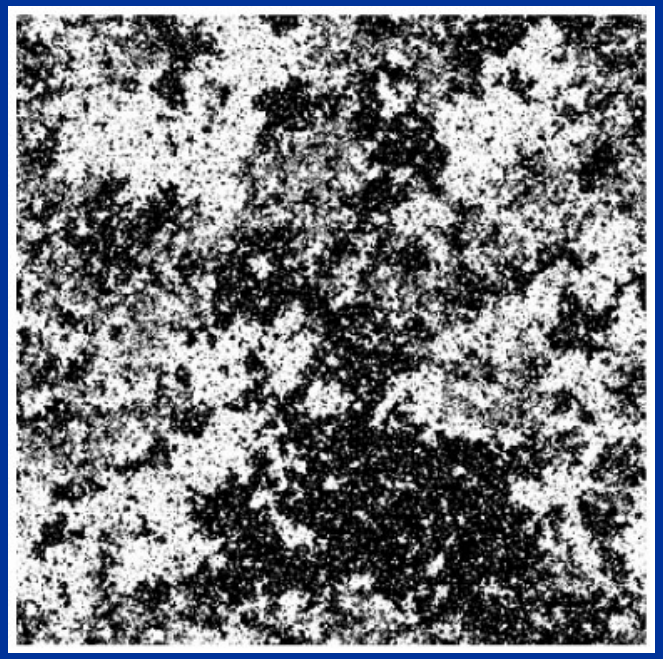
Dead leaves

- **Occlusion Models for Natural Images: A Statistical Study of a Scale-Invariant Dead Leaves Model.** Lee (IJCV 2001)

Material formation

- Brodatz, D100 Ising model

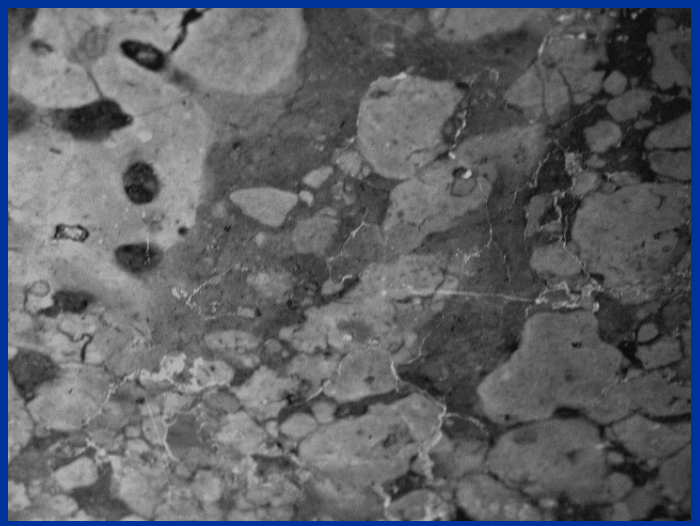




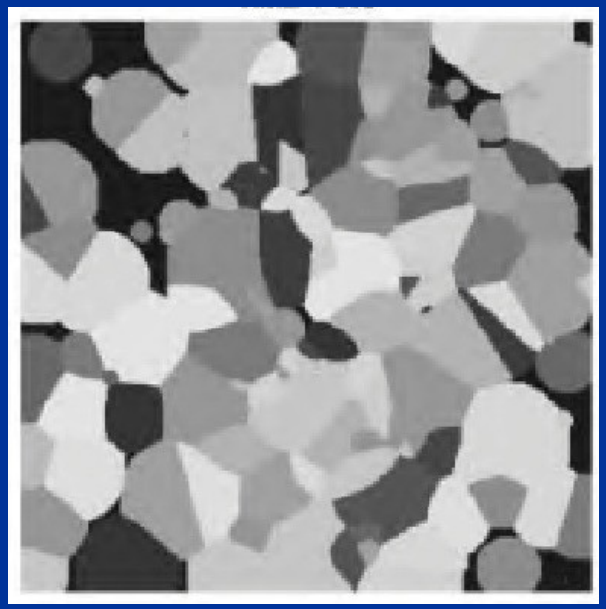
- James Sethna: Statistical Mechanics: Entropy, Order parameters, and Complexity (book)

Material formation

Marble (S. Lazebnik's database)



Johnson-Mehl model



- Capasso and Micheletti. Stochastic Geometry of Spatially Structured Birth and Growth Processes.

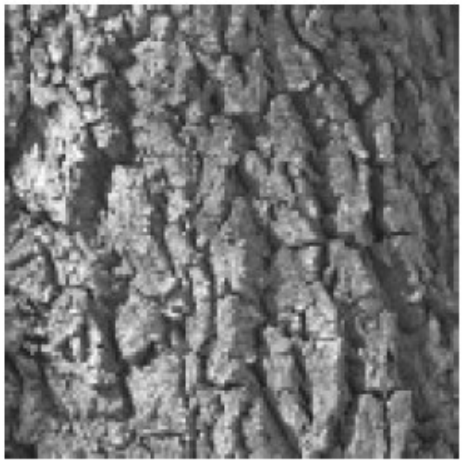
Texture Representation in Computer Vision

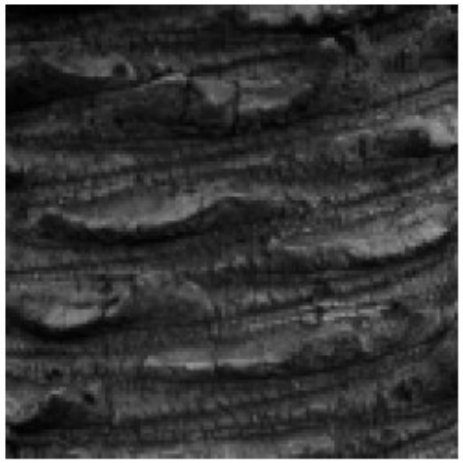
- Usually depends in regards to the task
- Recognition methods tend to use simple and more robust features. Aim at discriminability (Intra-class vs. Inter-class variability)
- Synthesis methods sometimes sample from the source image itself, thus arguably overfitting

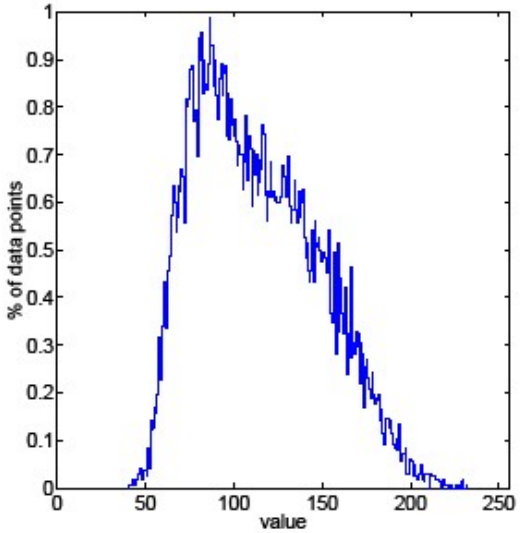
Recognition

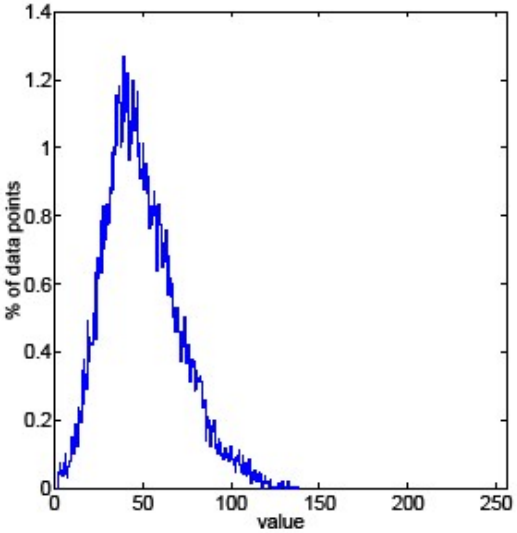
- Marginal statistics of filter responses (Review: Randen & Hussoy, PAMI 1999)
- Joint statistics of filter responses (Leung & Malik, ICCV'99)
- Filter, cluster, make histogram, compare using chi-sq (Leung & Malik, Varma & Zisserman, Forsyth 2004, ..)
- Extract affine-covariant regions, SPIN/SIFT, cluster, compare using EMD (Lazebnik, Schmid, Ponce)

Simple example





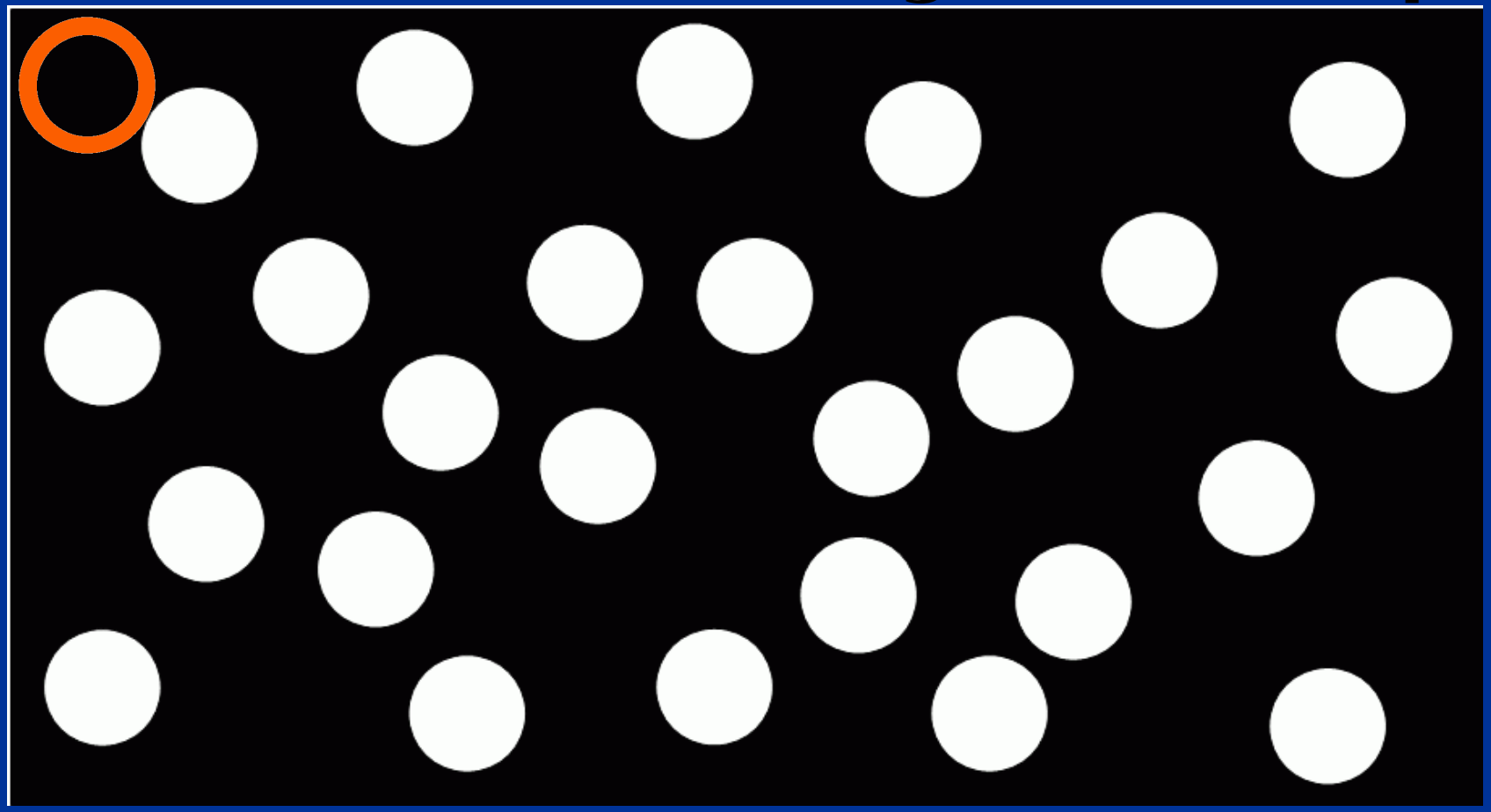




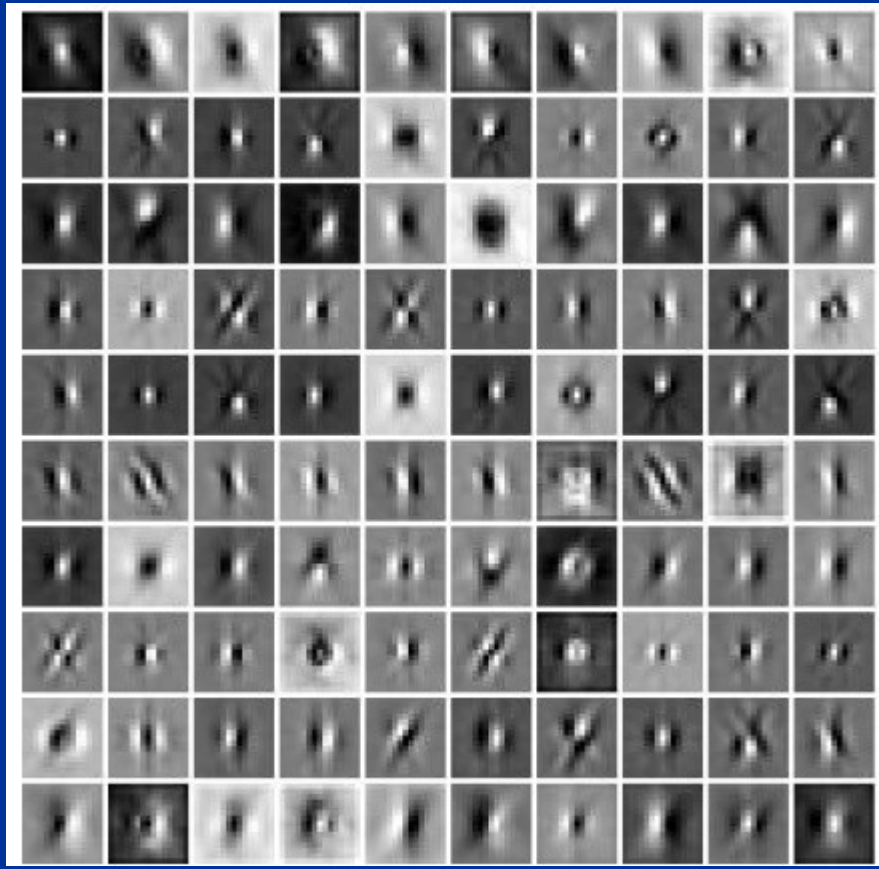
$E(I) = 113.2$
$\mathrm{std}(I) = 46.3$

$E(I) = 49.4$
$\mathrm{std}(I) = 25.0$

Filter, cluster, histogram, chi-sq



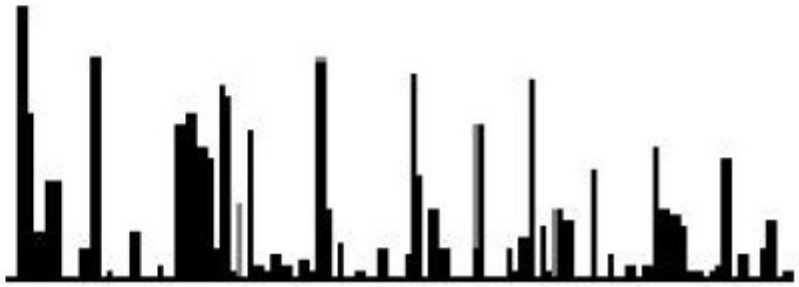
Filter, cluster, histogram, chi-sq



Textons = cluster centers

Filter, cluster, histogram, chi-sq

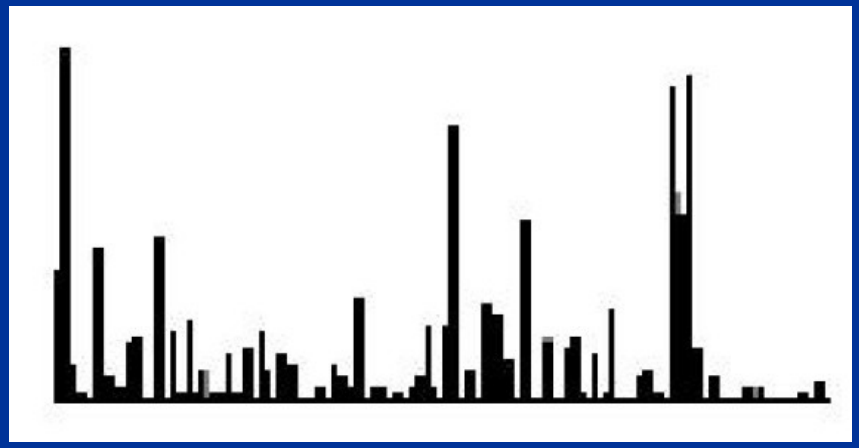
image

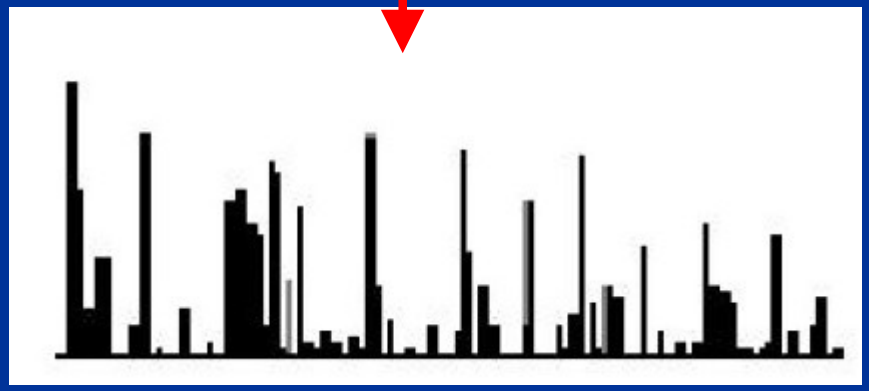


Texton histogram

Filter, cluster, histogram, chi-sq

$$\chi^2 = \sum_i \frac{(R_i - S_i)^2}{R_i + S_i}$$





Synthesis

- Methods which sample from the image (DeBonet & Viola 1998, Efros and Leung 1999)
- Methods which measure relatively simple statistics, then start from random noise and iteratively enforce the statistics to see fit (Heeger & Bergen 1995, Portilla & Simoncelli, IJCV2000)
- MRF modelling (Cross & Jain 1983, Zalesny et al 2005, ...)

What's the starting point?

- Ideally, a representation which enables both synthesis and recognition
- We'd like to have a texture synthesis and analysis system, modular and general enough to enable continuous addition of new models/constraints
- Example: Portilla & Simoncelli's algorithm (IJCV 2000)
- Using simple statistics

$$I \Rightarrow E\left[\left(f * I\right) \ldots\right]$$

Portilla and Simoncelli (P&S)

- Analysis: Measure a set of statistics on an image
- Synthesis: Start from random noise and iteratively change it to enforce the statistics
- Iteration:

$$I \leftarrow I + \lambda \frac{\partial E[(f * I)]}{\partial I}$$

such that

$$E\left[(f * I) \ldots\right] \rightarrow target$$

P&S: constraint enforcement

- Example:
- image variance

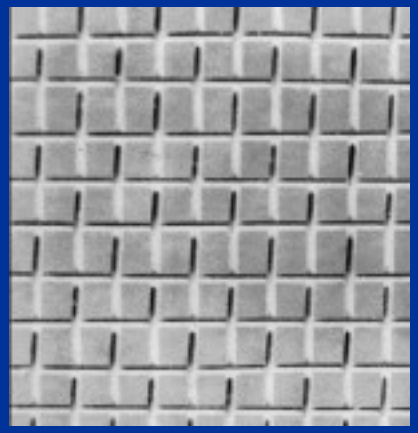
$$E\left[I^2\right] - E[I]^2$$

$$\frac{\partial E[I^2] - E[I]^2}{\partial I} \sim 2I - 2E[I]$$

$$I \leftarrow I + \lambda(I - E[I])$$

- Adjusting variance: scaling the image
- leads to eq. in lambda

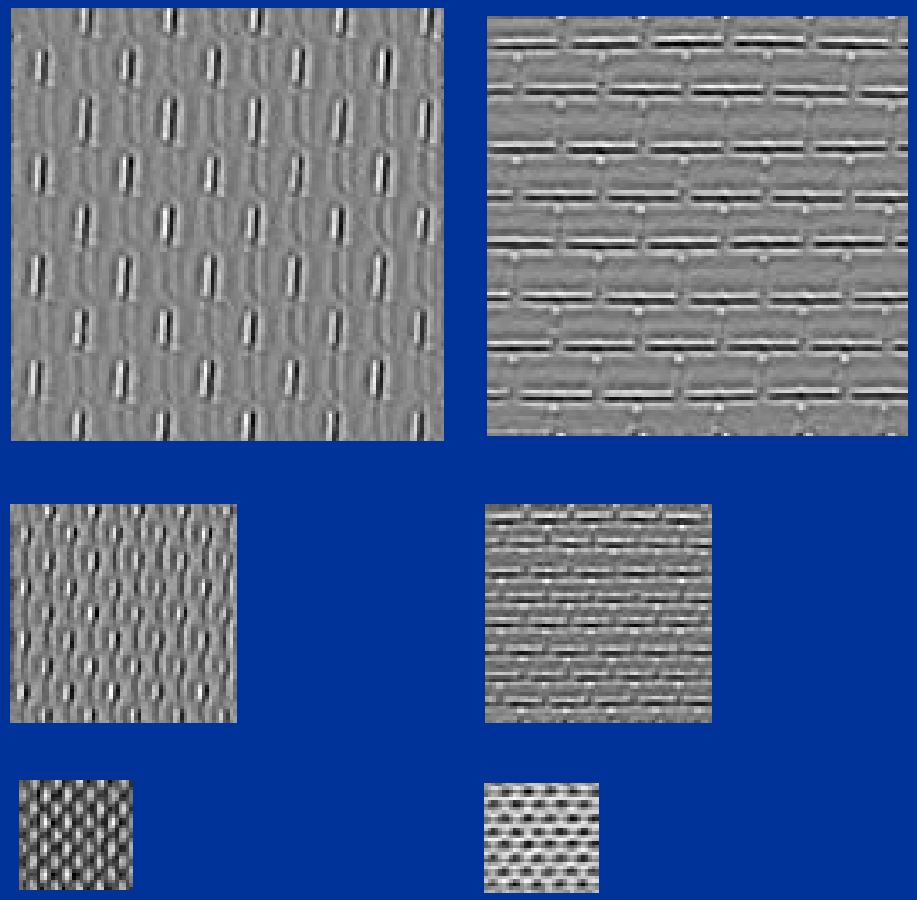
P&S: example

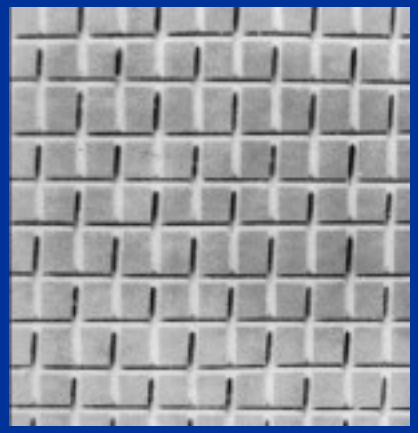


Brodatz, D1

P&S: pyramid decomposition

Oriented subbands

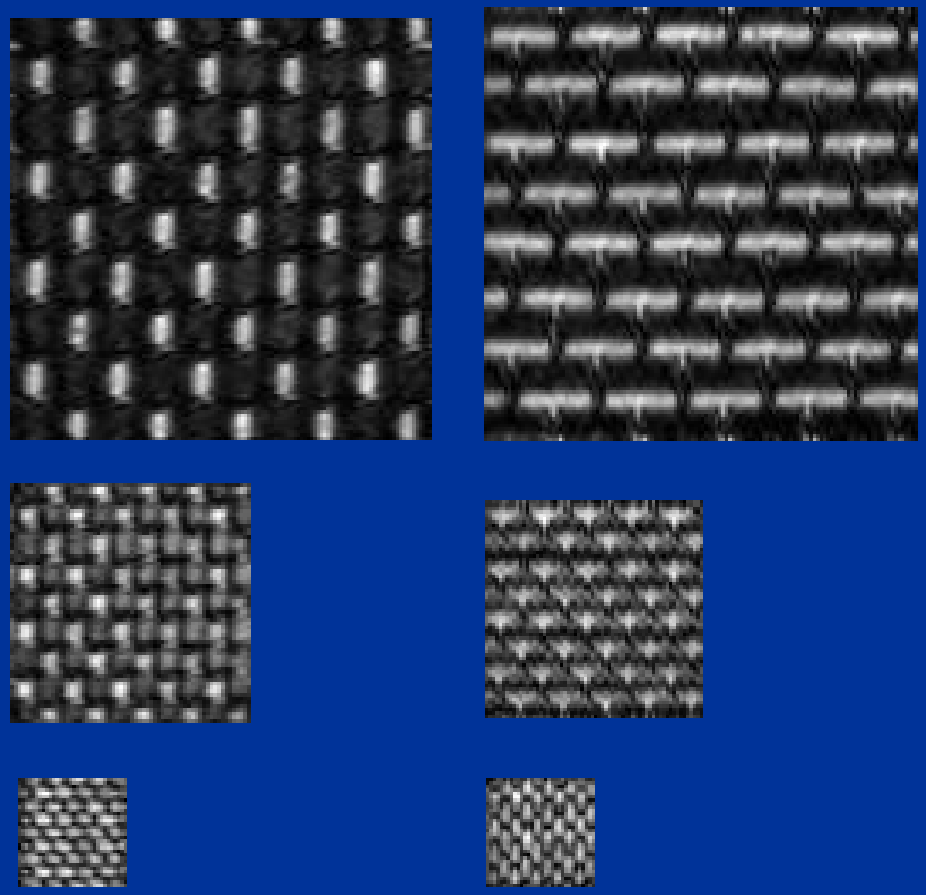




Brodatz, D1

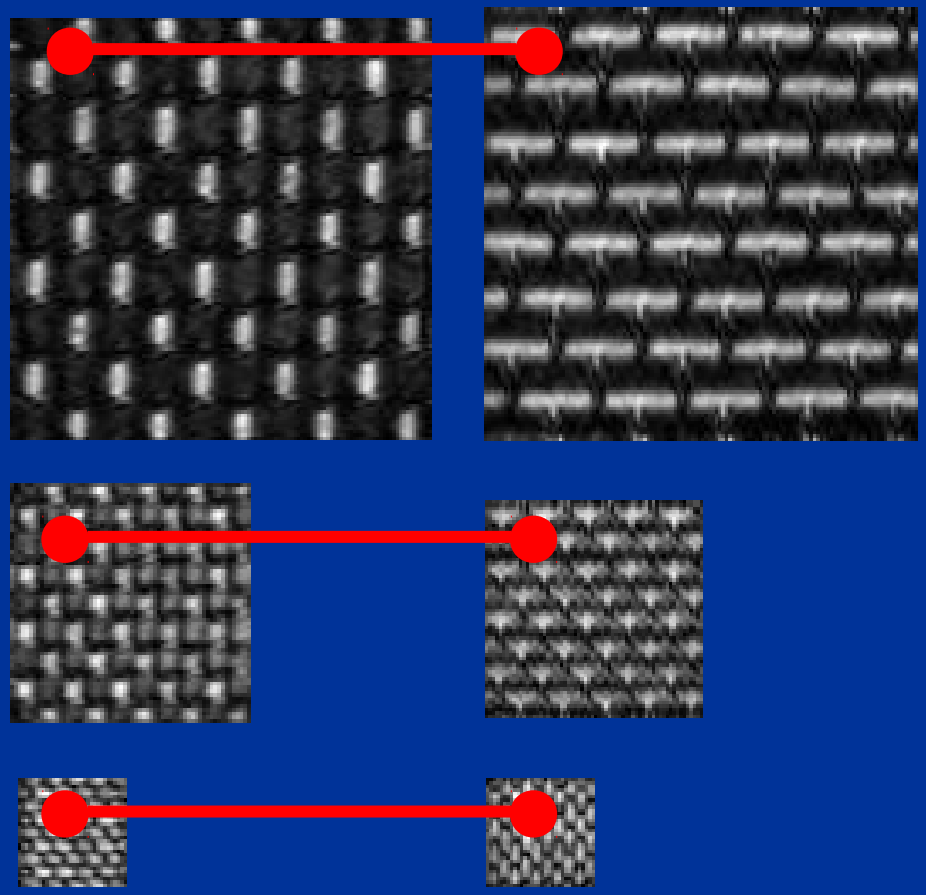
P&S: “complex cells”

Oriented subbands



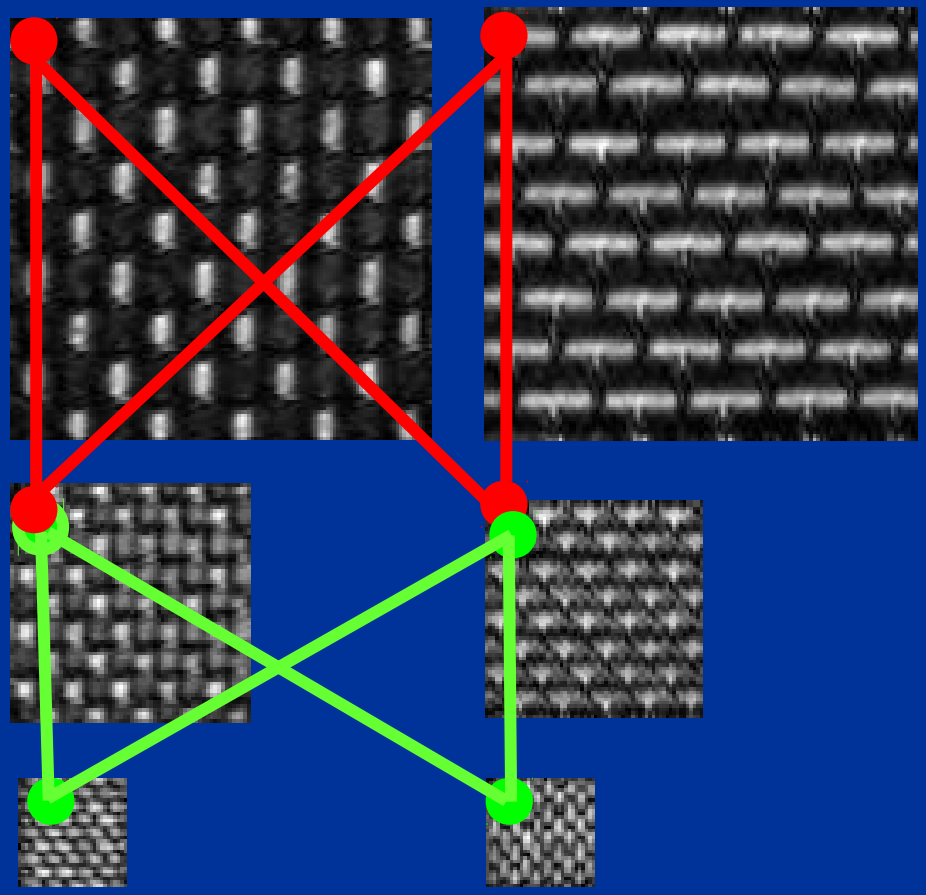
Magnitude of quadrature filters output (=complex cells reponse)

P&S: statistics used



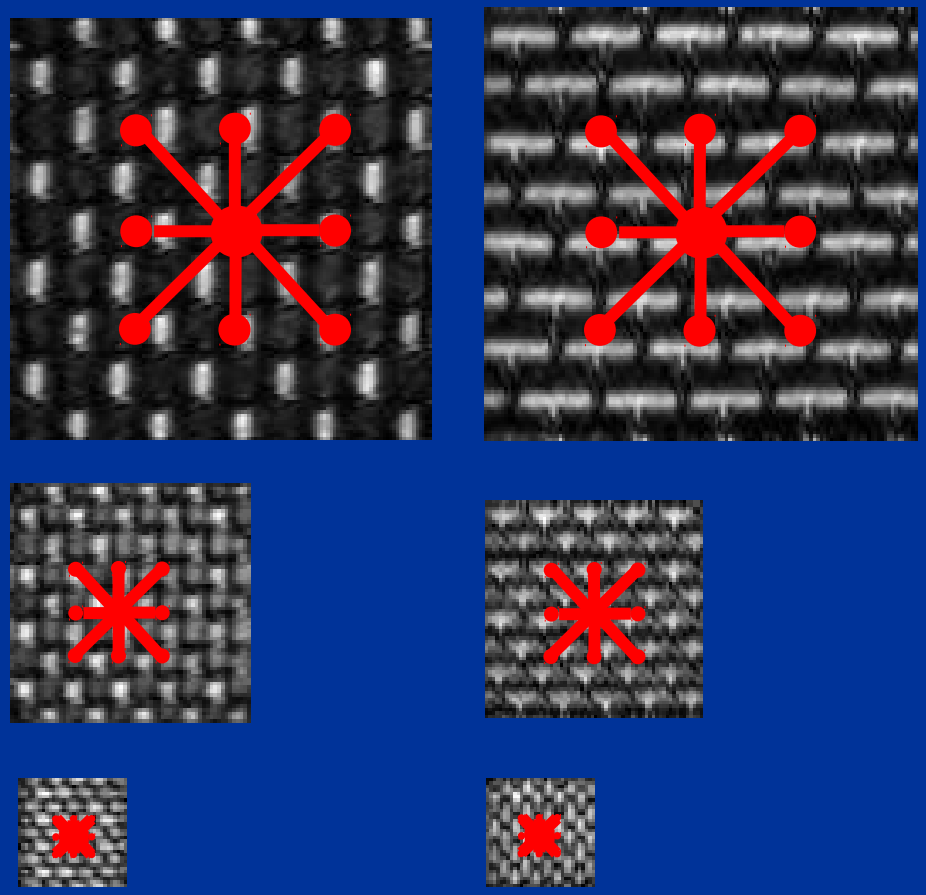
Correlation of subbands at the same scale

P&S: statistics used



Correlation of subbands across scales

P&S: statistics used



Center samples of autocorrelation

P&S: statistics used

Other constraints:

- Cross-scale phase statistics
- Autocorrelation of partially reconstructed images
- Marginal statistics of partially reconstructed images

Our synthesis system - proposal

- The statistics used in Portilla and Simoncelli are of the type:
- $$E\left[(f * I)^{\alpha}(g * I)^{\beta}\ldots(z * I)^{\theta}\right]$$
- These are actually low-order moments of the joint probability of filter responses
- Have a general texture synthesis system which is able to enforce constraints of this type

Our synthesis “language”

gl.c.partic = [ORI];

gl.c.conjpair = [YES];

gl.c.corr = [SAMESCALES];

gl.c.scale = [sc];

Our synthesis “language”

- Problem: actual statistics example (cross-scale phase statistics)

$$E\left[\frac{(f*I)(g*I)^2}{|g*I|}\right]$$

- Enforcing

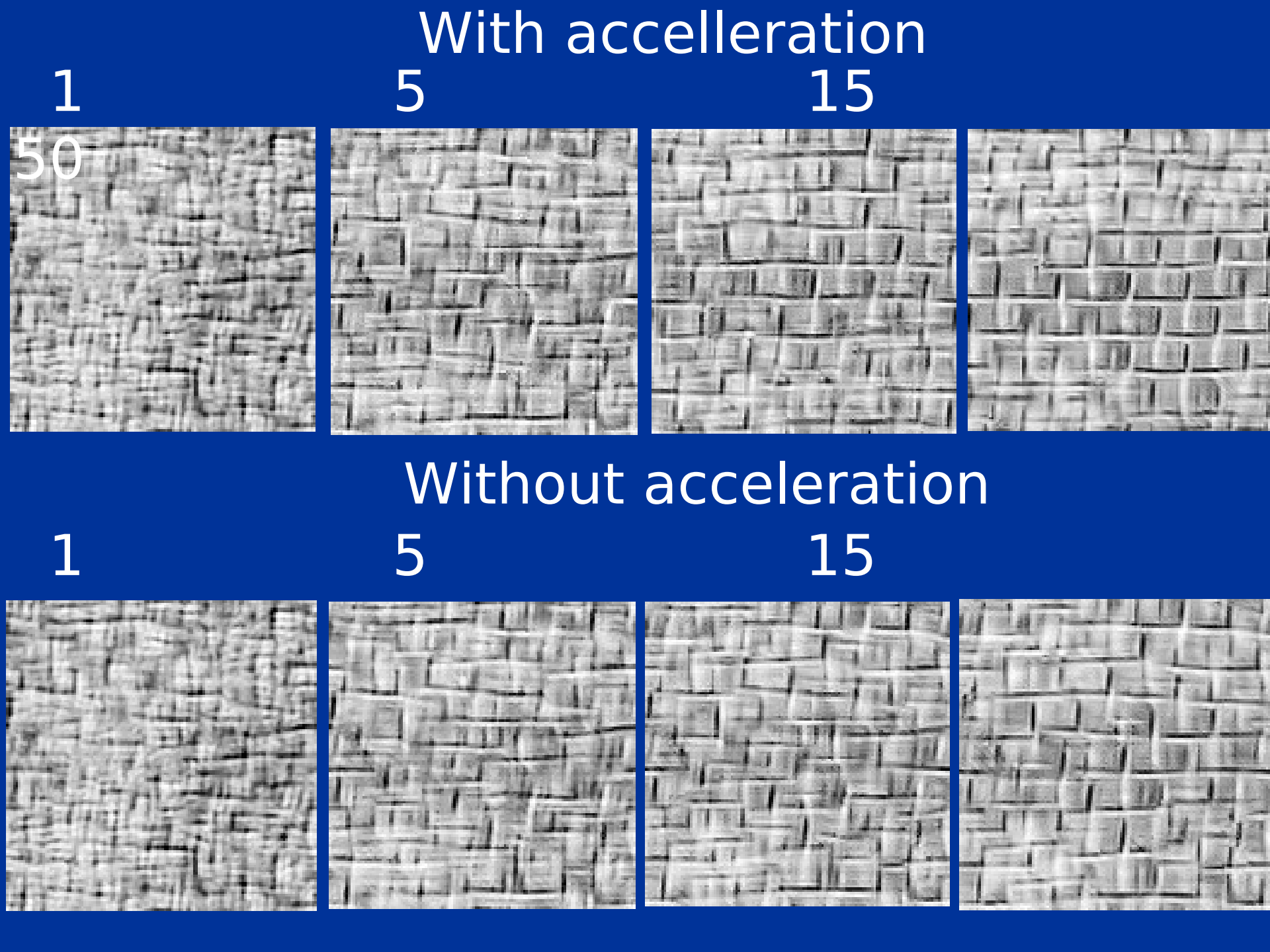
$$\downarrow$$

$$E\left[(f*I)(g*I)^2\right]$$

Results

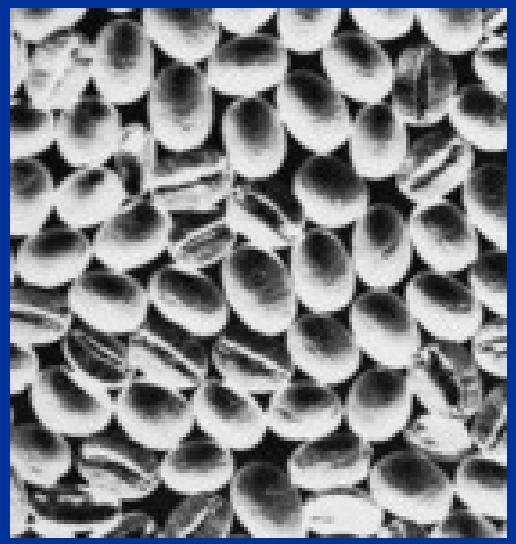
- Portilla & Simoncelli's algorithm is very skilfully optimized for success – in every aspect
- Example: "convergence accelerator"

  At the end of each iteration, exaggerate the change achieved at that iteration in order to reach faster performance

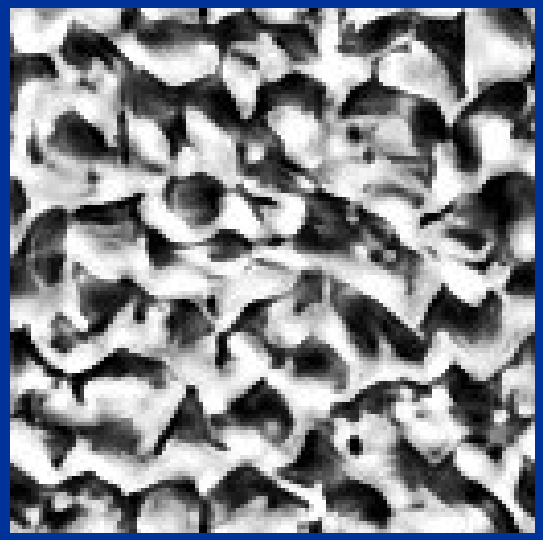

With accelleration
1
5
15
50
Without acceleration
1
5
15

Synthesis example

Brodatz, D74

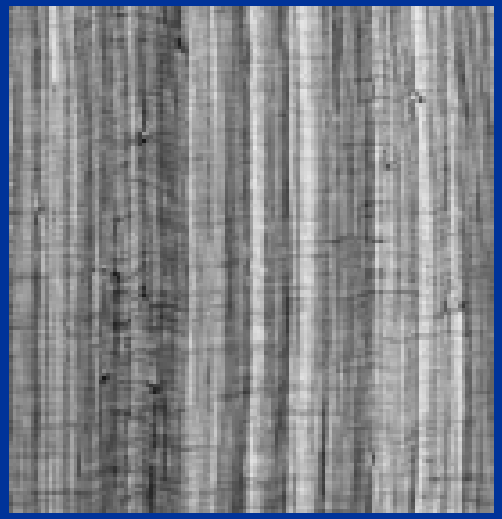


P&S

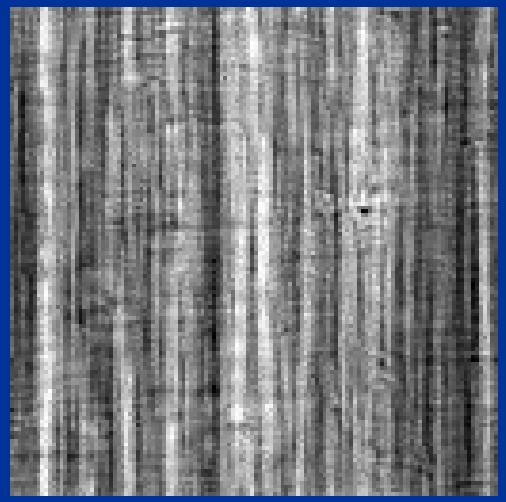


Synthesis example

Brodatz, D106



P&S



Conclusion

$$E\left[(f * I)^{\alpha}(g * I)^{\beta}\ldots(z * I)^{\theta}\right]$$

- These statistics are computed globally
- Problem when texture is not homogeneous
- Would be better to represent the joint filter responses distribution by e.g. mixture models, as opposed to moments