Diffusion on disordered fractals

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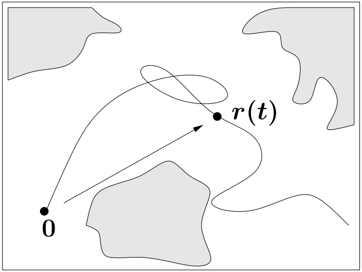
Anomalous Diffusion

Diffusion of particles in disordered materials

- inside a bulk
- on the surface (deposit)



Mean square displacement:

$$\langle r^2(t)\rangle \sim t^{\gamma} \qquad \gamma > 0$$

$\gamma < 1$ sub-diffusion
$\gamma = 1$ normal diffusion
$\gamma > 1$ super-diffusion

$r(t)$: Distance a particle has traversed in time t from its origin

Anomalous Diffusion

- Anomalous diffusion of water in biological tissues.
  M. Köpf, et al. *Biophys. J.*, 70(6):2950–2958, 1996.
- Anomalous diffusion of hydrogen in amorphous metals.
  W. Schirmacher, et al.; *Europhys. Lett.*, 13(6):523–529, 1990.
- Submonolayer growth with repulsive impurities.
  S. Liu, et al.; *Phys. Rev. Lett.*, 74(22):4495–4498, 1995.

→ Investigation of diffusion in disordered materials by numerical simulation

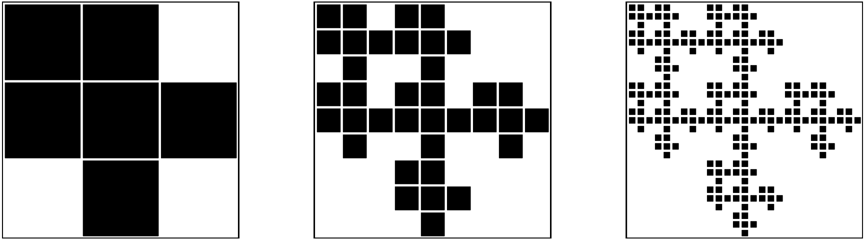
Porous Materials

Properties of porous materials:

- Holes, barriers and connections on all length scales
- Self-similar over certain length scales
- At larger length scales $\longrightarrow$ rather homogeneous
- Smallest length scale $\longrightarrow$ given by material

$\rightsquigarrow$ Aim: Modeling porous materials by fractals

Regular Sierpinski Carpets



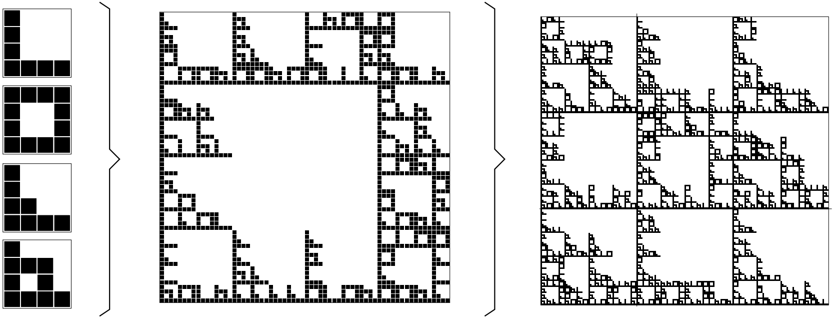
- Iteration repeated ad infinitum $\longrightarrow$ Sierpinski carpet
- k-fold iteration $\longrightarrow$ iterator of depth k

Fractal dimension: $M \sim L^{d_\mathrm{f}} \longrightarrow d_\mathrm{f} = \frac{\ln M}{\ln L}$

$\longrightarrow$ Transition from regular to randomized fractals

Randomized Sierpinski Carpets

- Random mixing of different generators
- Combining different iterators to one carpet

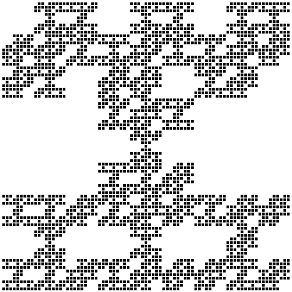


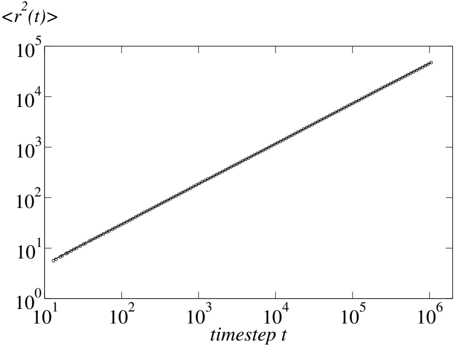
$\longrightarrow$ More realistic model: Self-similarity at certain length scales

- Smallest length scale: Depth of iterators ($\hat{=}$ pore size)
- Large length scales: Homogeneity

Random Walk Dimension

- Random walk dimension: $d_w = \frac{2}{\gamma}$
  $\rightarrow \langle r^2(t) \rangle \sim t^{\gamma} \rightarrow t \sim r^{d_w} \rightarrow$ power law behavior
  $\rightarrow$ also valid for randomized Sierpinski carpets





D. Anh, et al.; *Europhys. Lett.*, 70(1):109-115, 2005

Open Questions

- What happens by mixing different generators with $\langle d_w \rangle$?

  Investigations by Reis with regular random fractals (different from our construction procedure)

  F. Reis; *J. Phys.A: Math. Gen.*,29(24):7803-7810, 1996

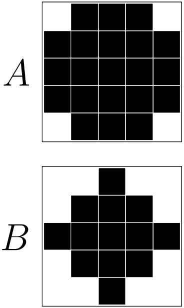
  $\longrightarrow$ No significant changes in exponents

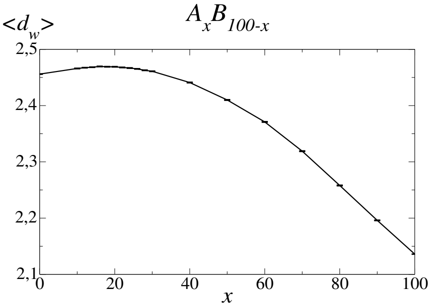
$\Rightarrow$ But we obtained quite different results!

Results

D. Anh, et al.; *Europhys. Lett.*, 70(1):109-115, 2005

- Mixing pairs of different generators
- Two generators of different d_f and different d_w



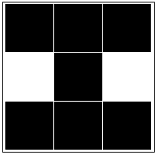


- Maximum of $\langle d_w \rangle$ can be observed

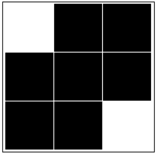
Results

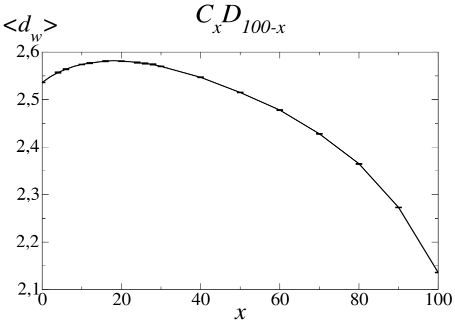
- Two generators with different d_w but same d_f

C



D





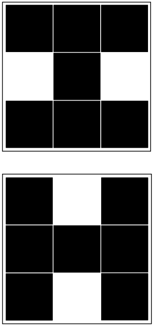
- Maximum of $\langle d_\mathrm{w} \rangle$ can be observed

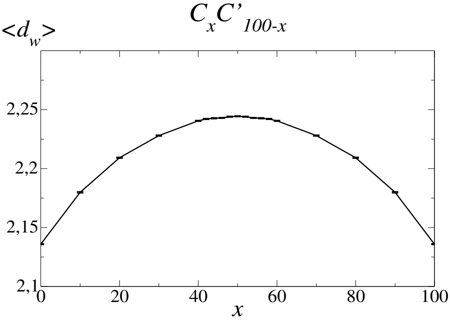
Results

- Two generators with same d_w and same d_f

C

C'

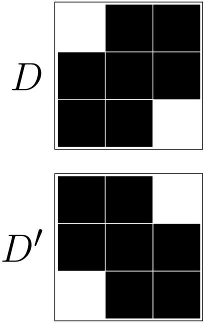


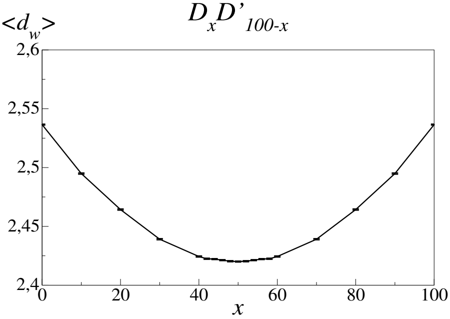


- Variation even for similar d_w and d_f

Results

- Two generators with same d_w and same d_f





- More disorder can enhance diffusion

Question

Can we predict dynamical properties just by knowing the structure?

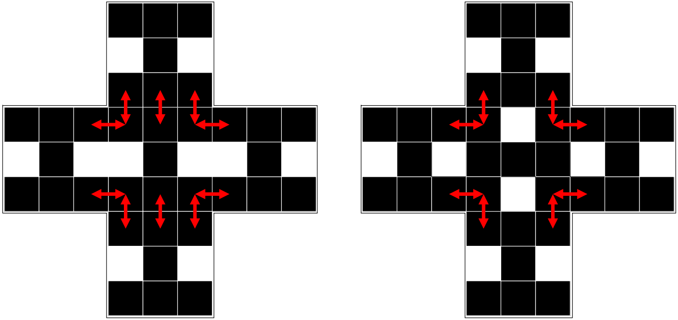
If yes: Analysis porous materials for experiments:

- Mass
- Connectivity
- ...

$\Rightarrow$ Explanation of dynamics due to structural properties

Connection Points

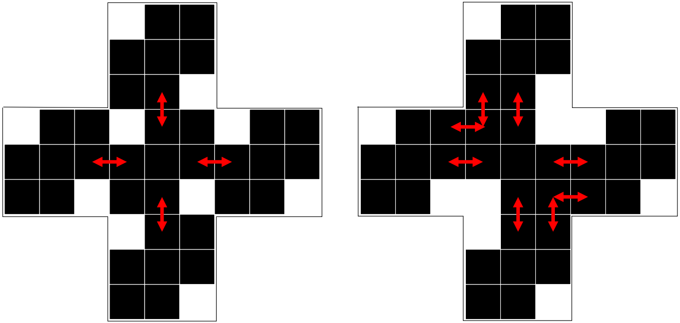
Structural property: Connection points between generators C and C‘



→ Slowing down of diffusion

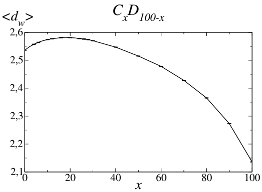
Connection Points

Structural property: Connection points between generators D and D'



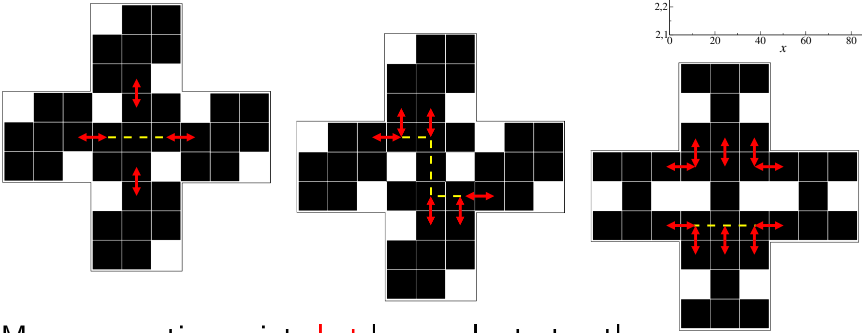
→ Enhancement of diffusion

Shortest Path



Structural property:

Shortest path through generators



More connection points but longer shortest path

$\longrightarrow$ Slowing down of diffusion

Summary

From structure to dynamics:

- Increasing number of connection points $\longrightarrow$ enhancement of diffusion
- For longer shortest paths $\longrightarrow$ diffusion slows down

$\rightsquigarrow$ Number of connection point and shortest path length are important for $\langle d_w \rangle$

Acknowledgment

Thank you for your attention!