Patchy memories in low dimensions: Disorder, noise, and genesis; recovering after erasure

Jie Yang, AAM, Syracuse University
PRB 96, 214208 (2017) & to be submitted

Creighton Thomas, Olivia White; support from the NSF

KITP - Memory Formation in Matter - February 20, 2018

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Theory & computation:
explore possibilities for particular class of memory

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Many examples of memories in matter

Stone and chisel / Paper and pencil
Photograph / Phonograph
Computer: e.g., magnetic domains
Associative memory in neural nets (Hopfield model)

Kaiser effect: remembers largest strain
Kovacs effect: remembers waiting time
Return-point memory in magnets: Nested hysteresis curves
Pulse duration memory
Multiple transient memories (charge density waves; non-Brownian suspensions)
Multiple memories in jammed solids

Echoes: spin; (anharmonic) phonon
Aging, rejuvenation and memory in glasses
Dynamical systems - remembering initial conditions

Shape-memory alloys
Designing in function: memory

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Localized control

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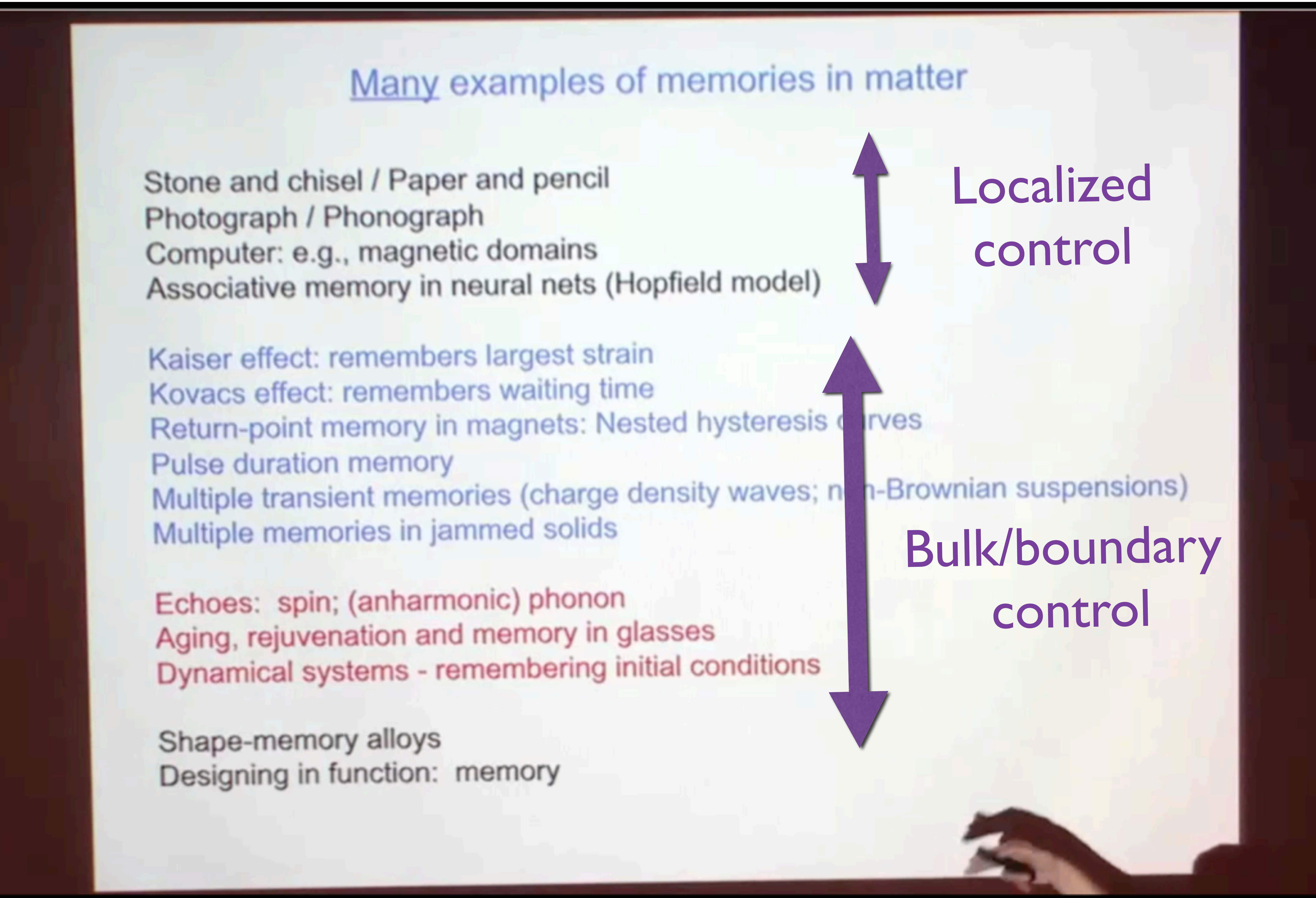

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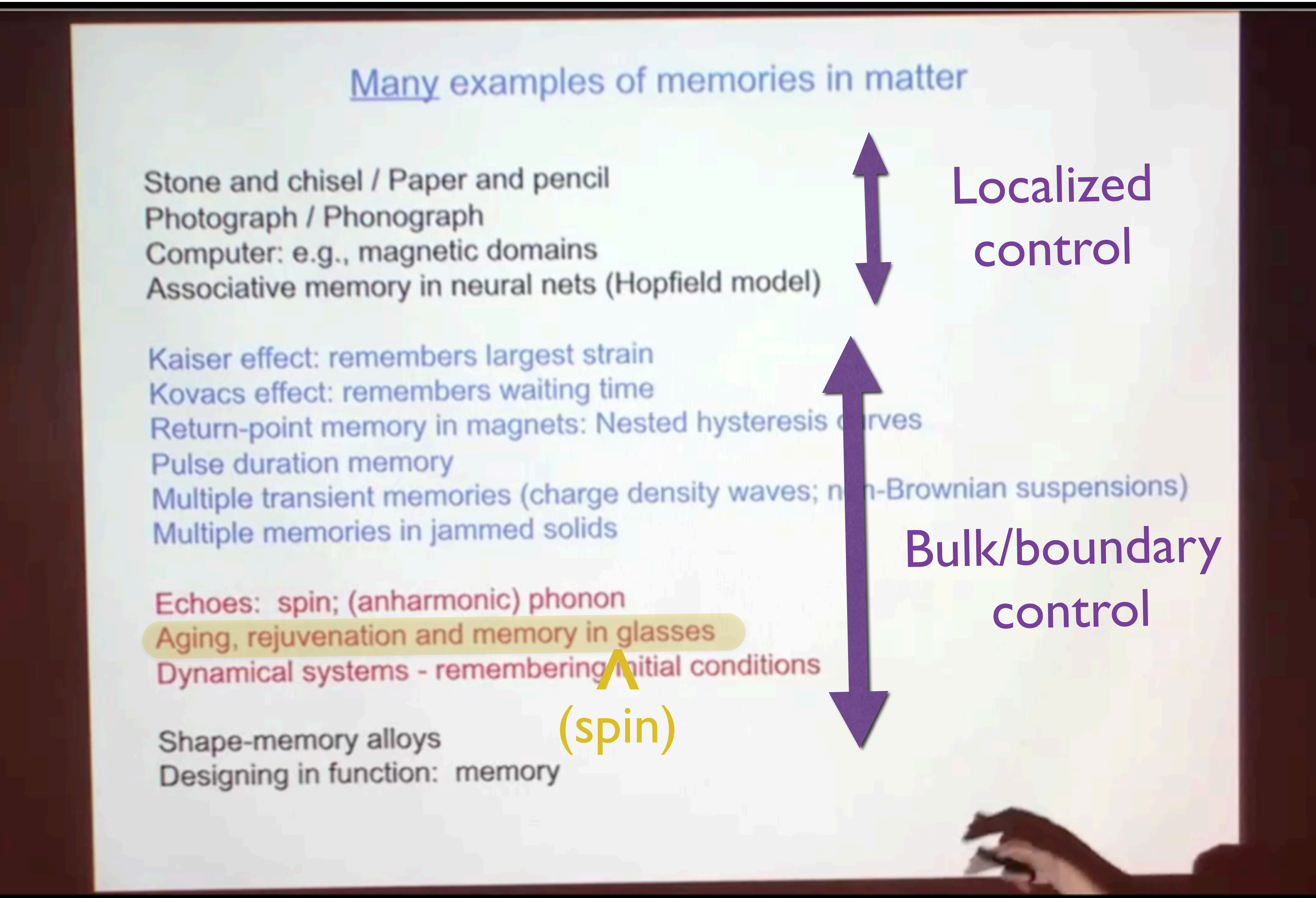

Spin glass - memory features

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No design - random, frustrated interactions

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- Expt: bulk susceptibility

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2D, 1D Ising spin glass, *T*=0

$\mathcal{H}(\vec{s}) = -\sum_{<ij>} J_{ij} s_i s_j$

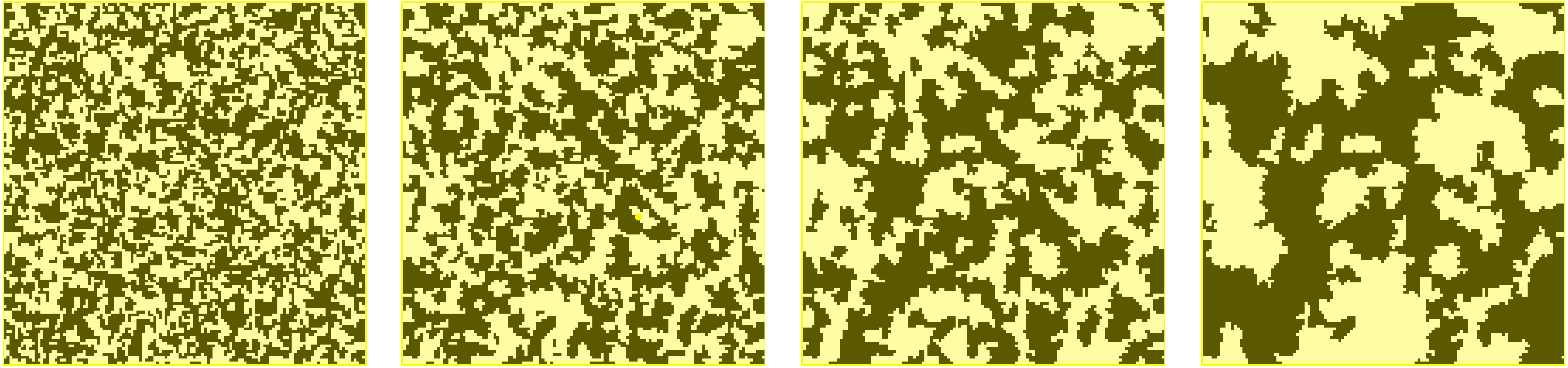
Square/linear/ladder lattice, index i for spins,
Ising spins $s_i = \pm 1$,
Gaussian distributed J_{ij}, mean 0

Two global ground states

Two configurations denoted by A, $\overline{A}$
Pictures: *not* s_i, instead whether
s_i aligned with A or $\overline{A}$

Coarsening via patches

Coarsening via patches



$\ell = 1$ $\ell = 2$ $\ell = 4$ $\ell = 8$

Start with random spins, ℓ is patch size

Dark = A phase, light = $\overline{A}$ phase.

Inspired by, compare with, other spin glass work:

Ye, Gheissari, Machta, Newman, Stein (2016):

Detailed study with of single spin flips

Dependence of local $T = 0$ aging on dimensionality

Chanal and Krauth (2010):

Multi-scale coupling from the past in 2DISG $T \neq 0$

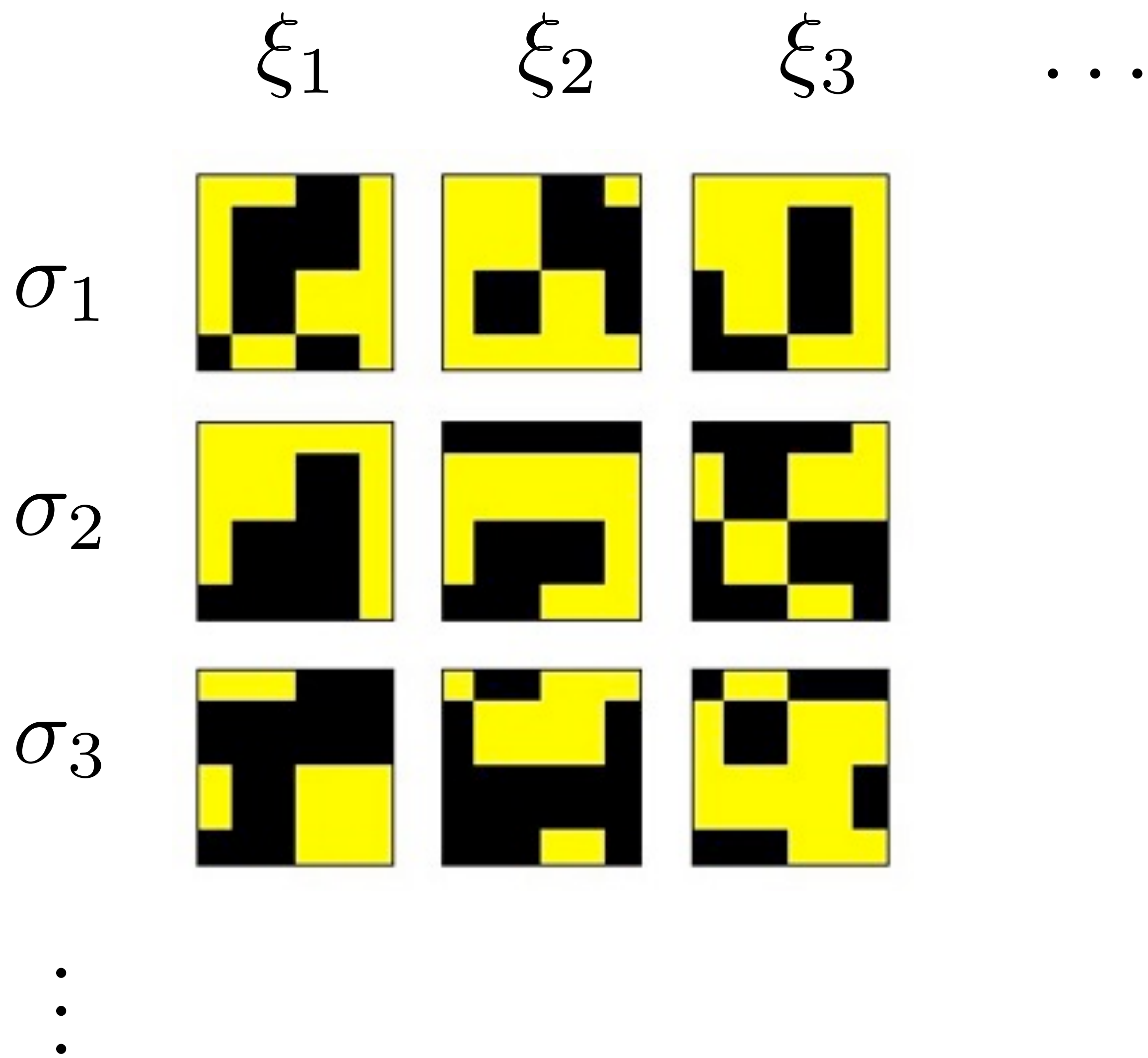
Found: final configuration not dependent on initial configuration at high T

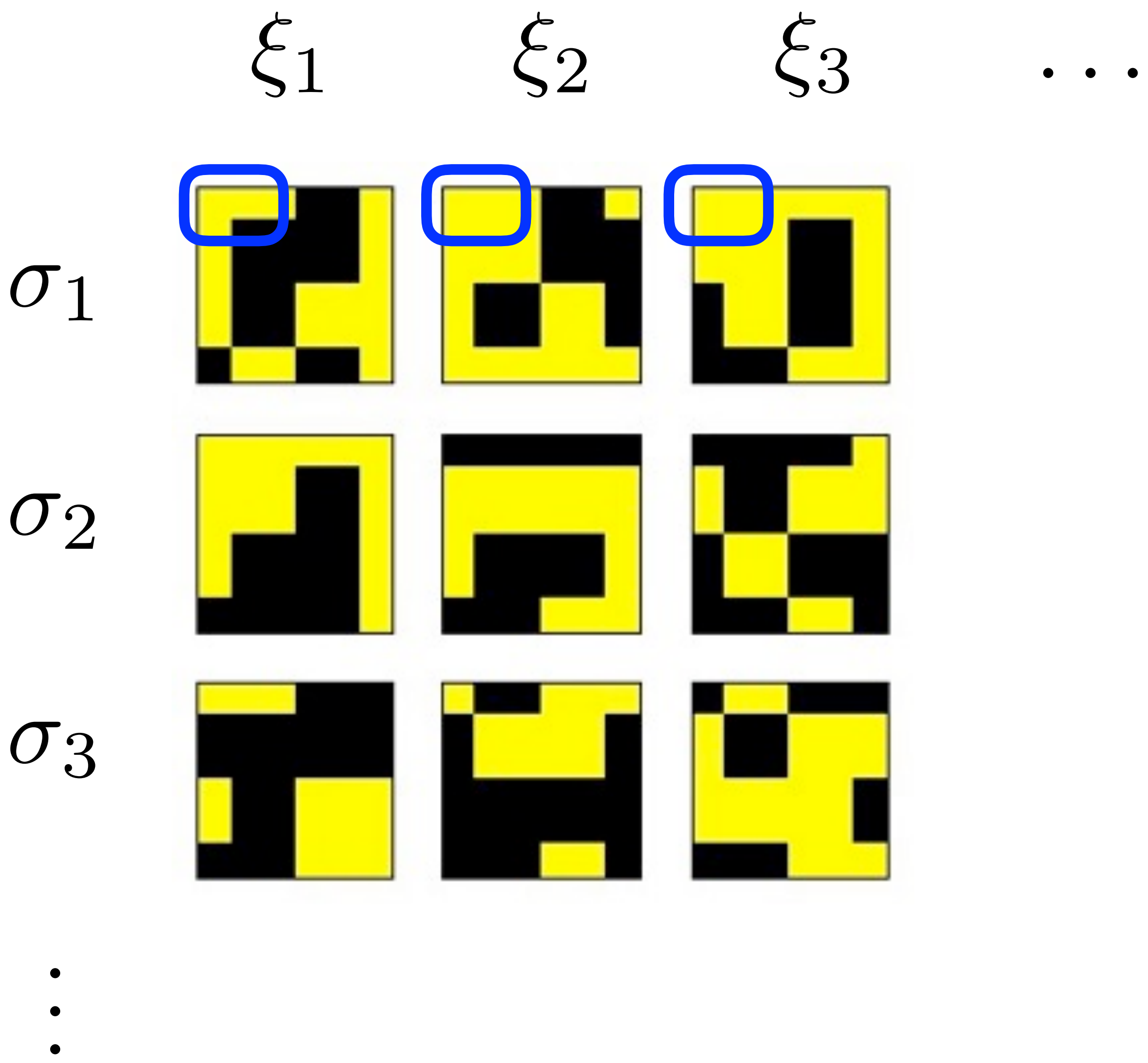
Nature/environment,
Genesis/initial conditions,
Nurture/history of noise

Given

- environment $= J_{ij}$
- genesis $=$ initial spins σ_i
- nurture $=$ history of patch placements $=$ random noise ξ

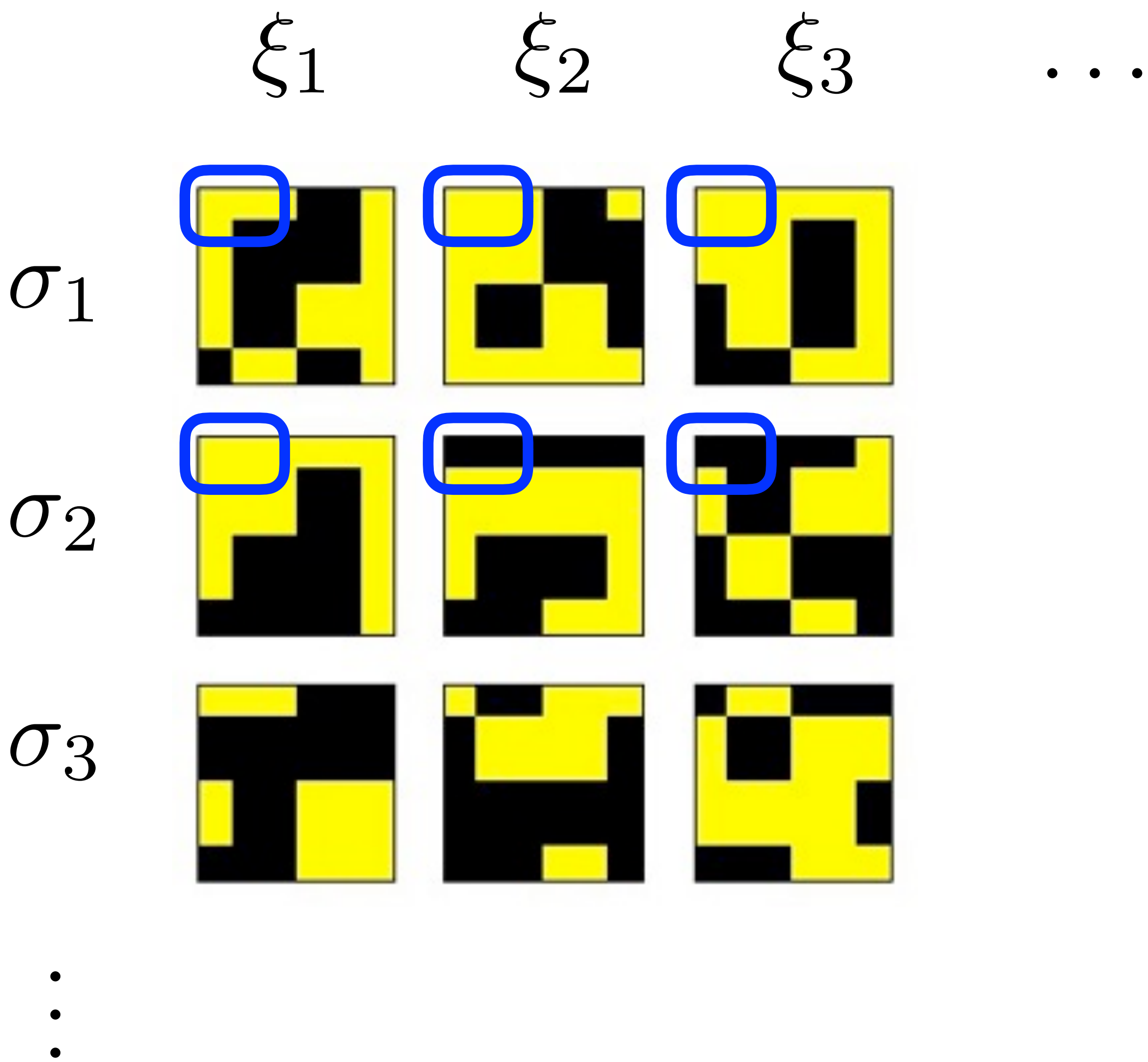
Find configurations $s_i(J_{ij}, \sigma, \xi)$





Average over noise history ξ:

$\langle s_0 s_1 \rangle(\sigma_1)$



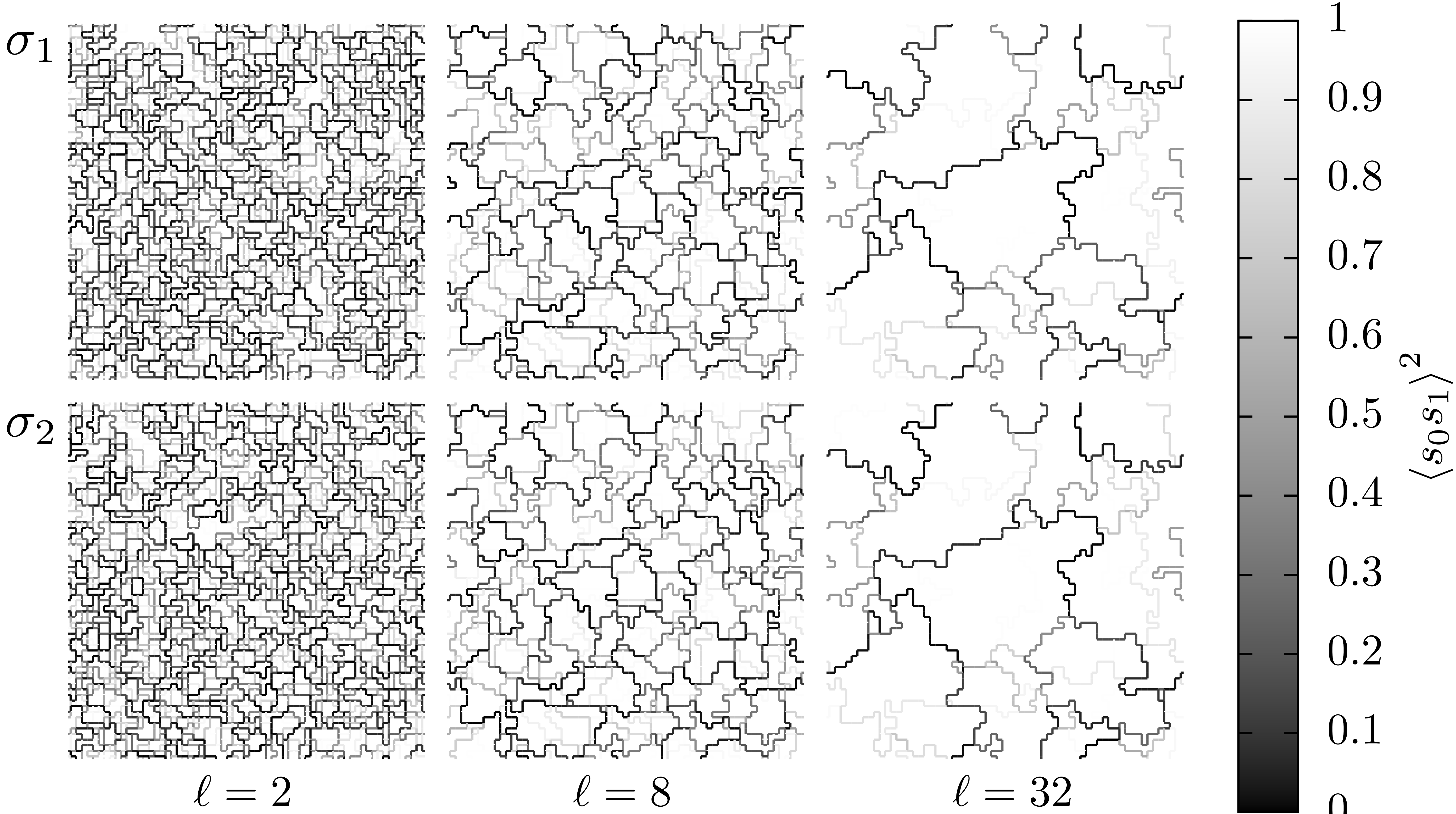
Average over noise history ξ:

$\langle s_0 s_1 \rangle (\sigma_1)$

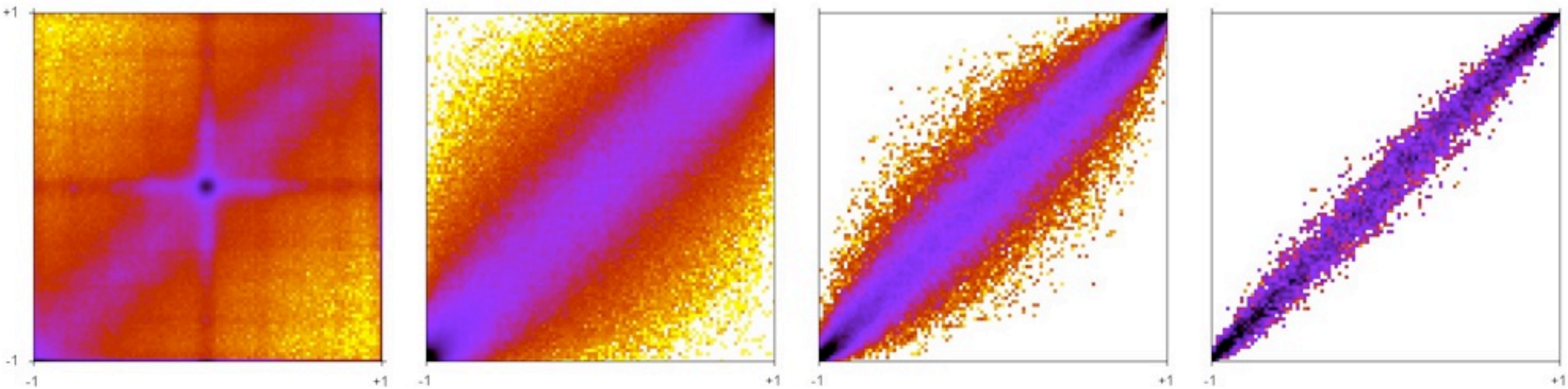
$\langle s_0 s_1 \rangle (\sigma_2)$

Two initial configs / Multiple noise histories

dark (light) bonds = "floppy" (rigid) with respect to noise



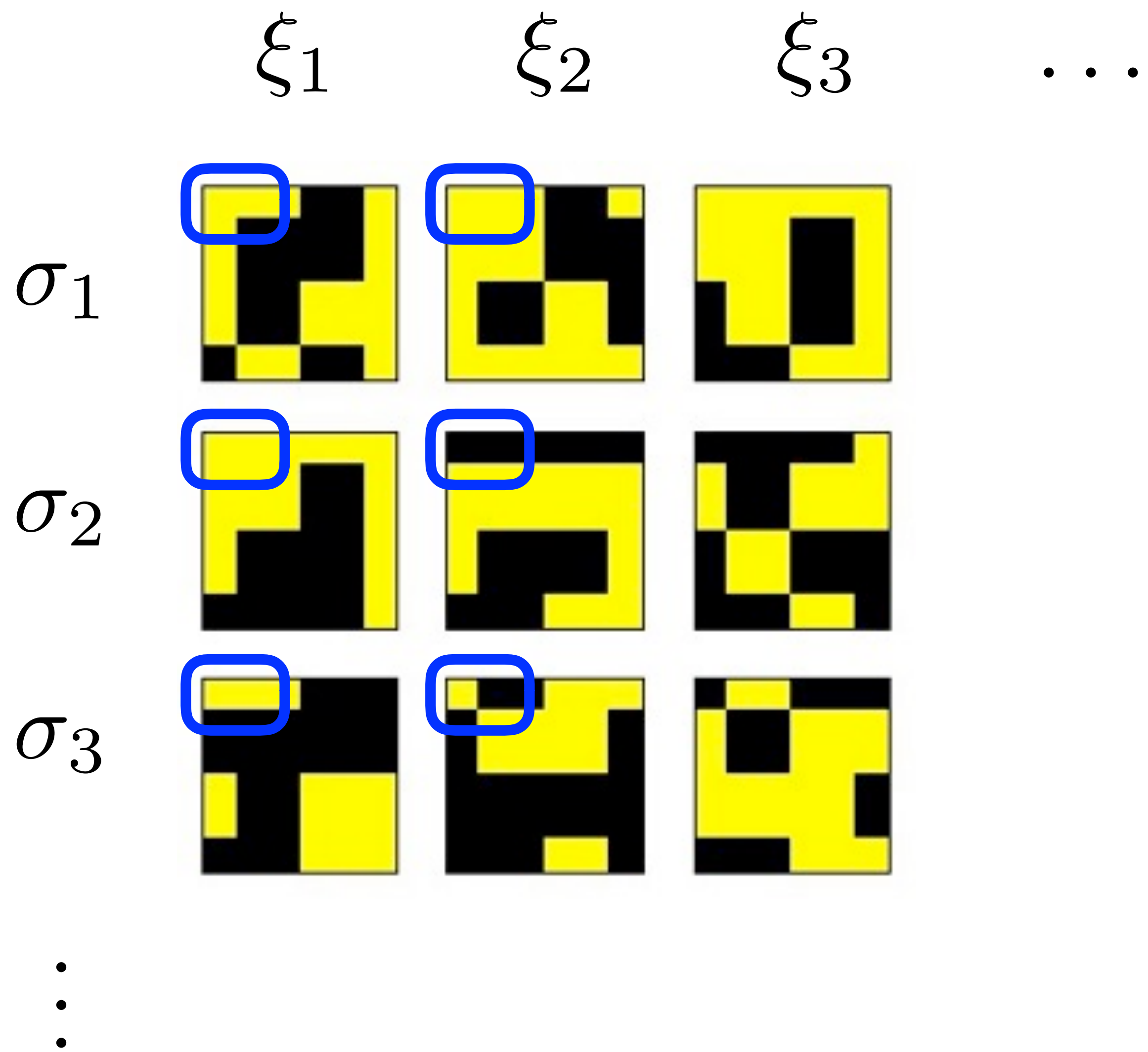
Noise-history-averaged bond correlations for two initial σ,
$\langle s_i s_j \rangle (J_{ij}, \sigma_2)$ vs. $\langle s_i s_j \rangle (J_{ij}, \sigma_1)$



$\ell = 1$ $\ell = 4$ $\ell = 16$ $\ell = 64$

(all bonds $s_i s_j$, 50 samples J_{ij} with 256^2 spins,
2 initial conditions $\sigma_{1,2}$, 1000 noise histories ξ)

Average over initial conditions σ:



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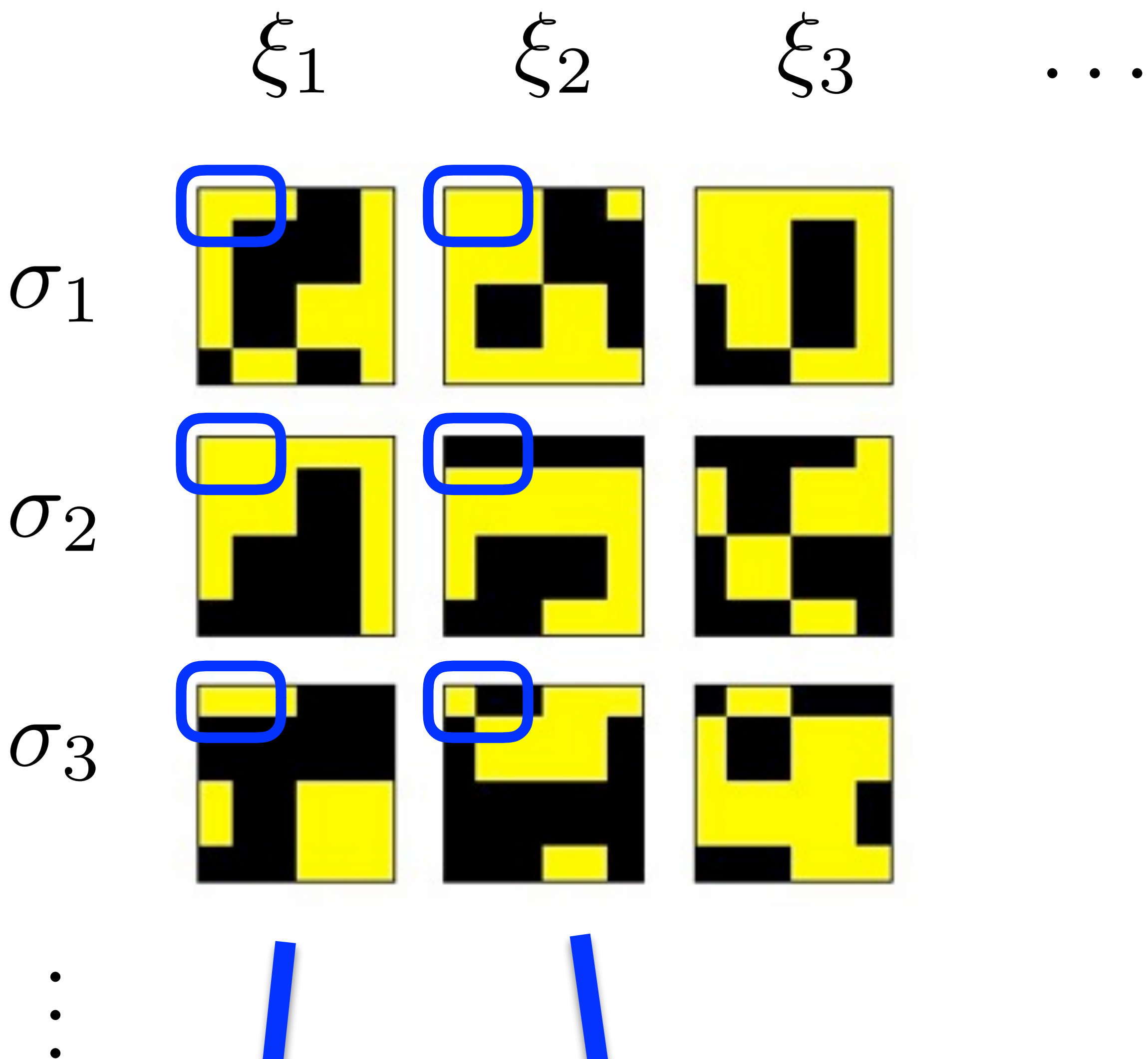

Average over initial conditions σ:

$[s_0 s_1]\,(J_{ij}, \xi_1)$ $[s_0 s_1]\,(J_{ij}, \xi_2)$

Two noise histories / Multiple initial configs

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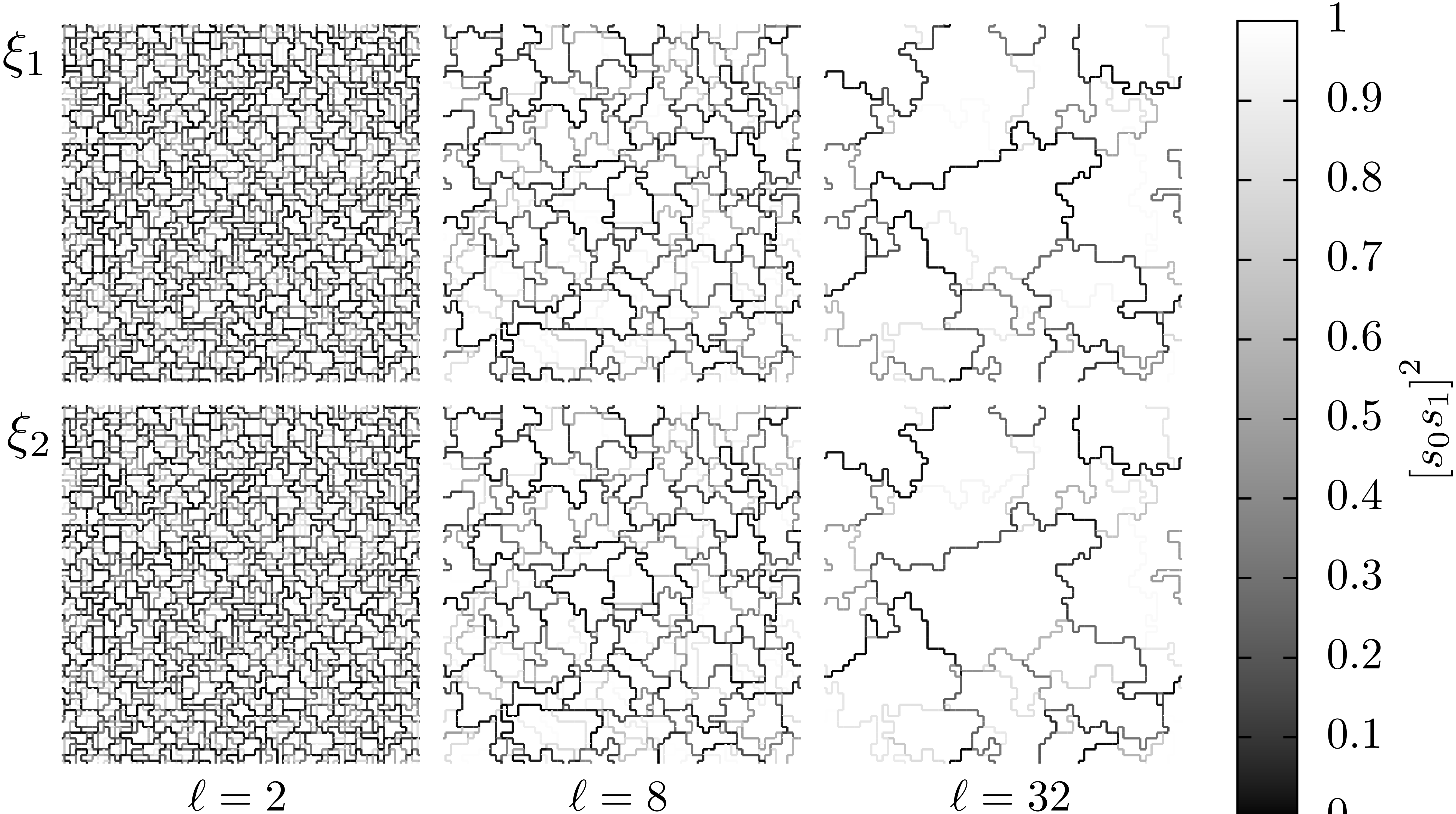
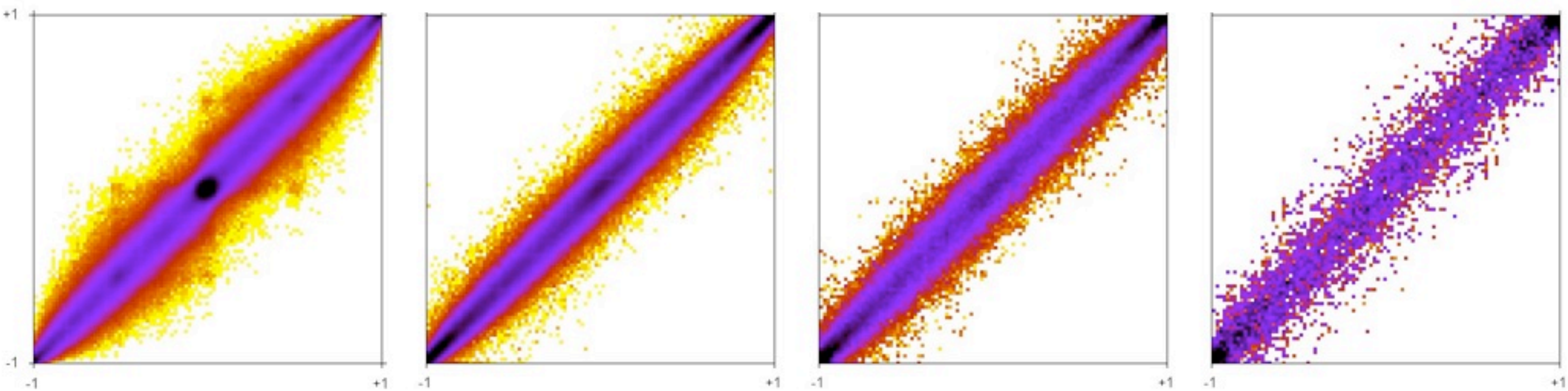


Initial-configuration-averaged bond correlations for two noise histories ξ,
$\langle s_i s_j \rangle (J_{ij}, \xi_2)$ vs. $\langle s_i s_j \rangle (J_{ij}, \xi_1)$



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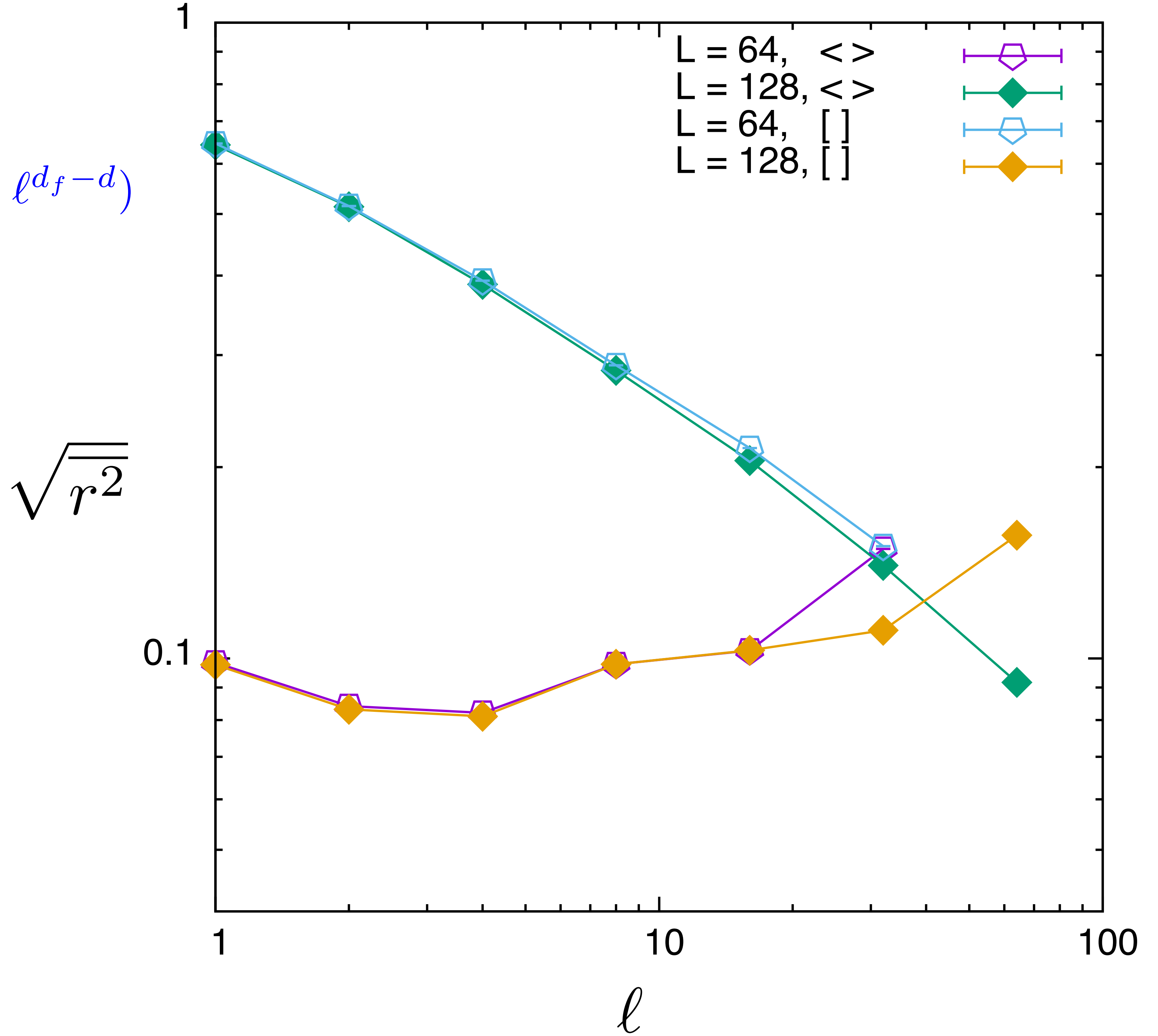
For "non-rigid" bonds, define

$$r = \langle s_0 s_1 \rangle(\sigma) - \langle s_0 s_1 \rangle(\sigma')$$

or

$$r = [s_0 s_1]\,(\xi) - [s_0 s_1]\,(\xi')$$

(Fraction of non-rigid bonds $\sim \ell^{d_f - d}$)



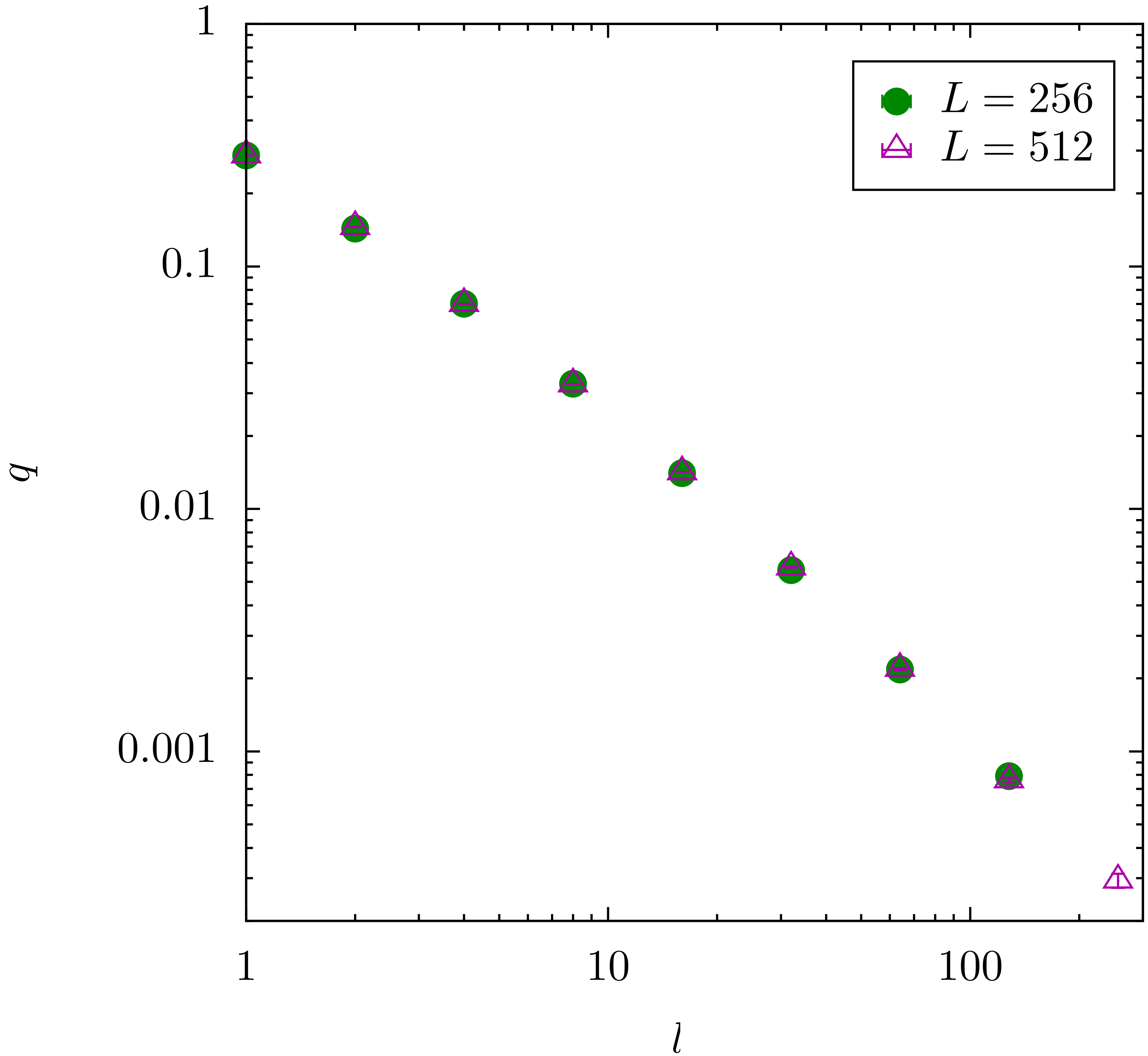
Noise, genesis, environment w/frustration

- Both $\langle \ldots \rangle$ and $[\ldots]$: same rigid domains, floppy walls, given J_{ij}.
- Average over histories ξ: floppiness independent of initial configuration σ.
- Average over starts σ: floppiness depends on history ξ.
- Even for $[\ldots]$, domain walls not fixed by history.
- ... scale-invariant uncertainty arising from initial conditions.
- Cf. partial-ordering/coupling-from-the-past: $\xi \rightarrow$ outcome.

Memory test

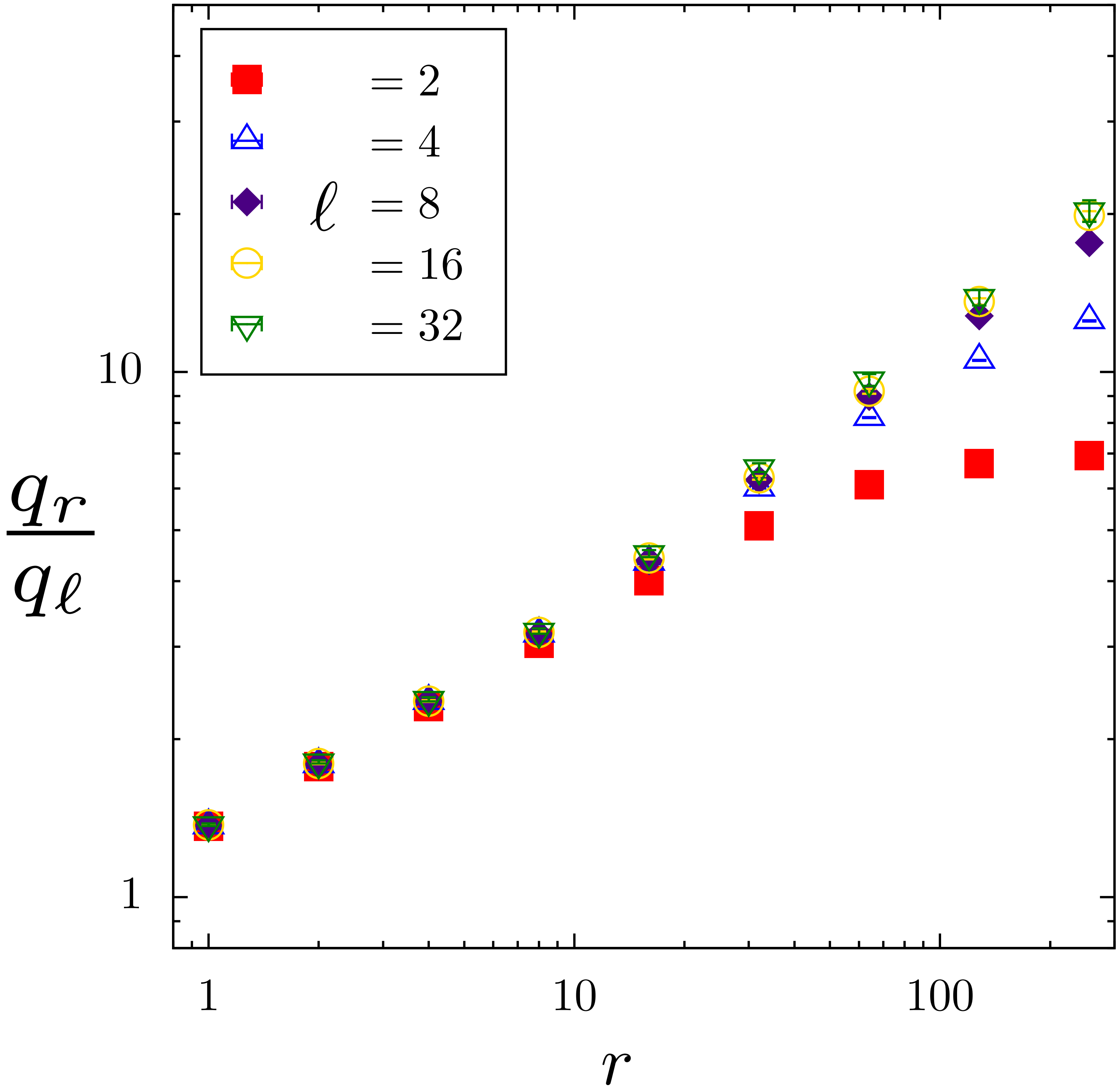
1. Given J_{ij}, set spins to global ground state $s_i^A(\{J_{ij}\})$.
2. Scramble disorder - independent J'_{ij}.
3. Grow patches to scale ℓ under new landscape.
4. Reset to J_{ij}.
5. Recover by growing patches to scale r.
6. Track overlap $q = N^{-1} \sum_i s_i^A s_i$ all along.

2D aging, couplings J'



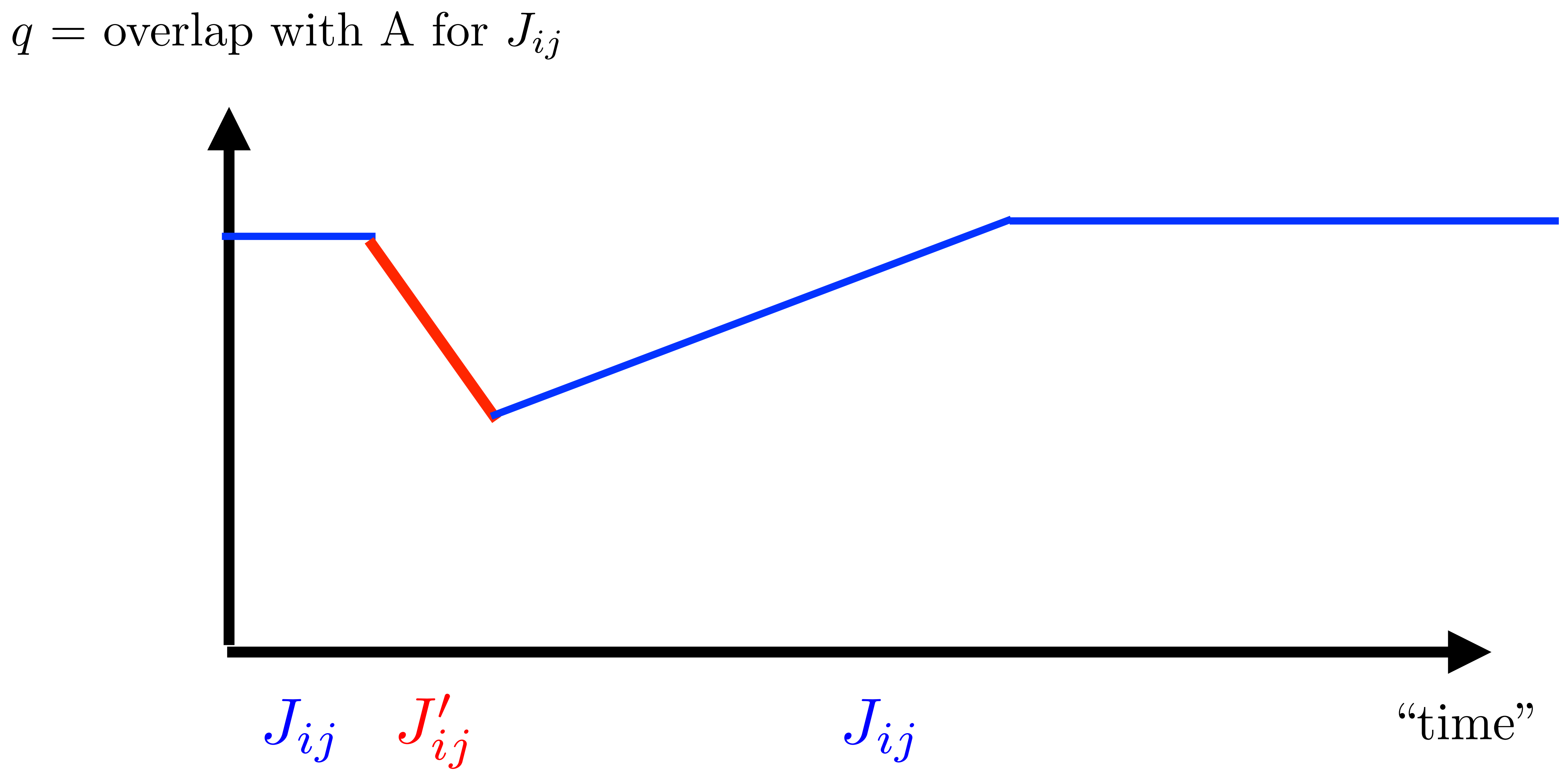
$$q \sim \ell^{-1.4}$$

2D recovery, couplings J



$$\frac{q_r}{q_\ell} \sim r^{0.5\pm0.05}$$

$d = 2$



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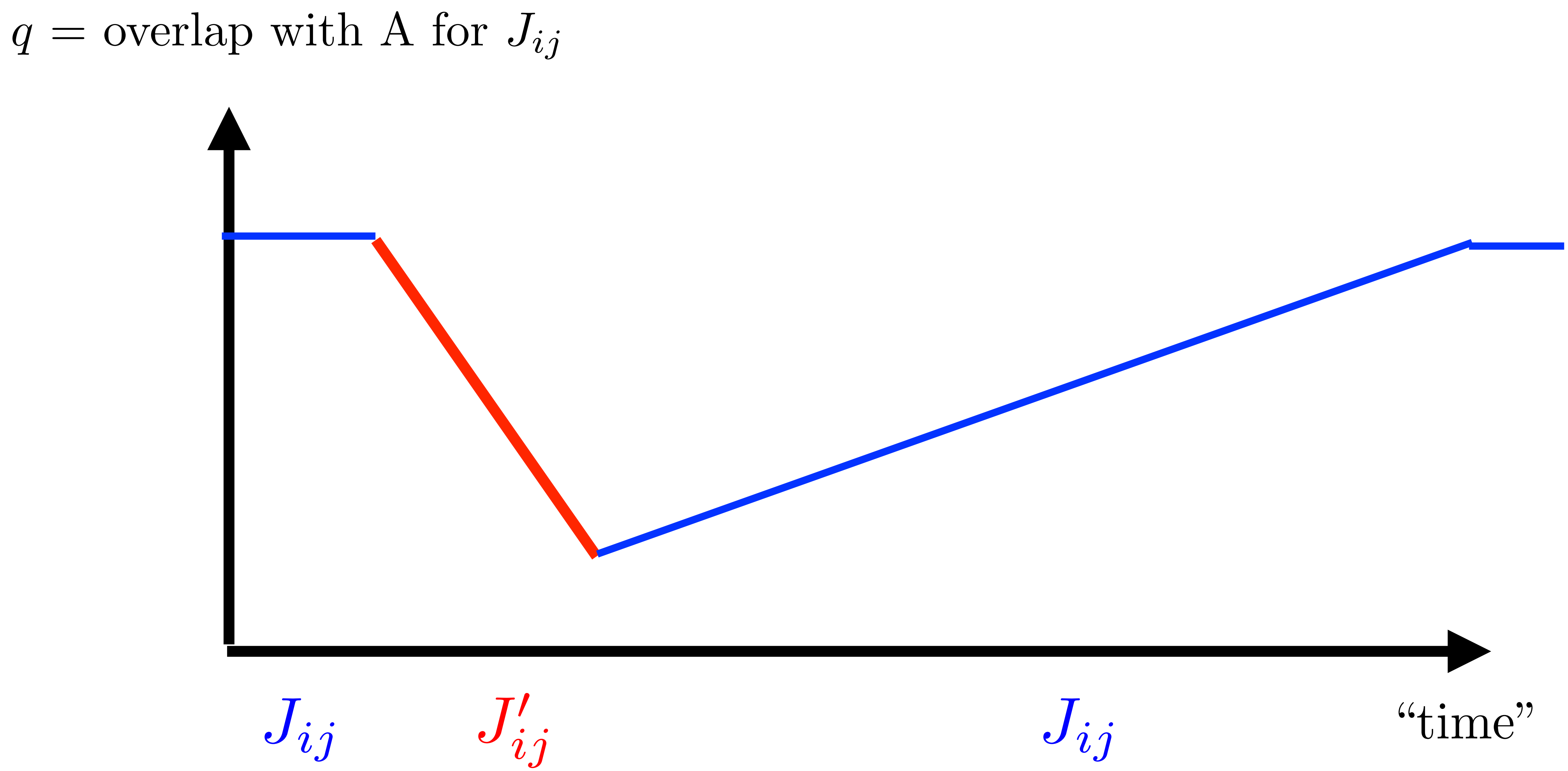

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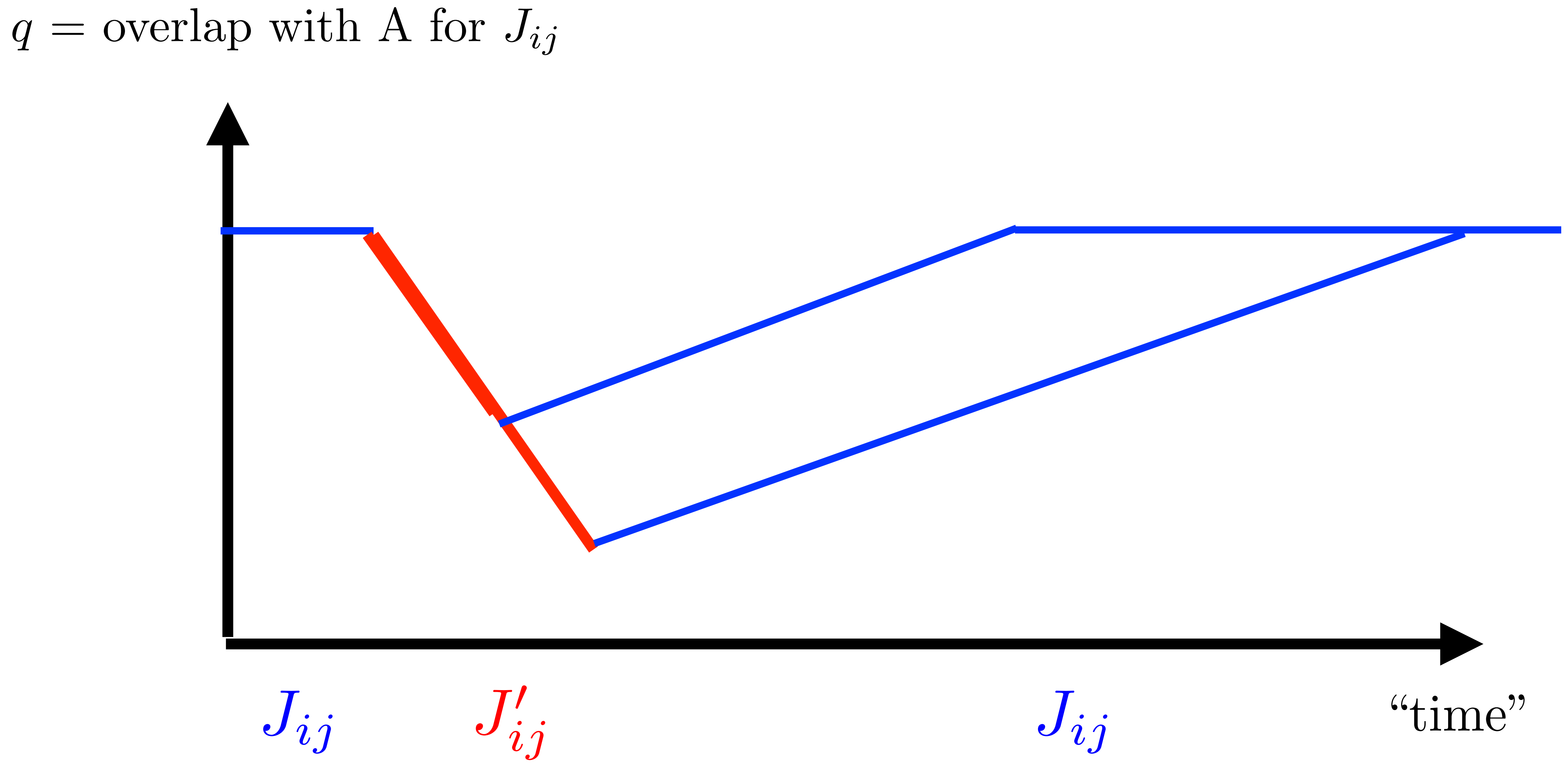

Recovery length for 2D patches

Scaling argument:

Full recovery at

$$r_c \sim \ell^{1.4/0.5} = \ell^{2.8}$$

$\Rightarrow$ Recovery at scales $r_c \gg$ than aging scale ℓ

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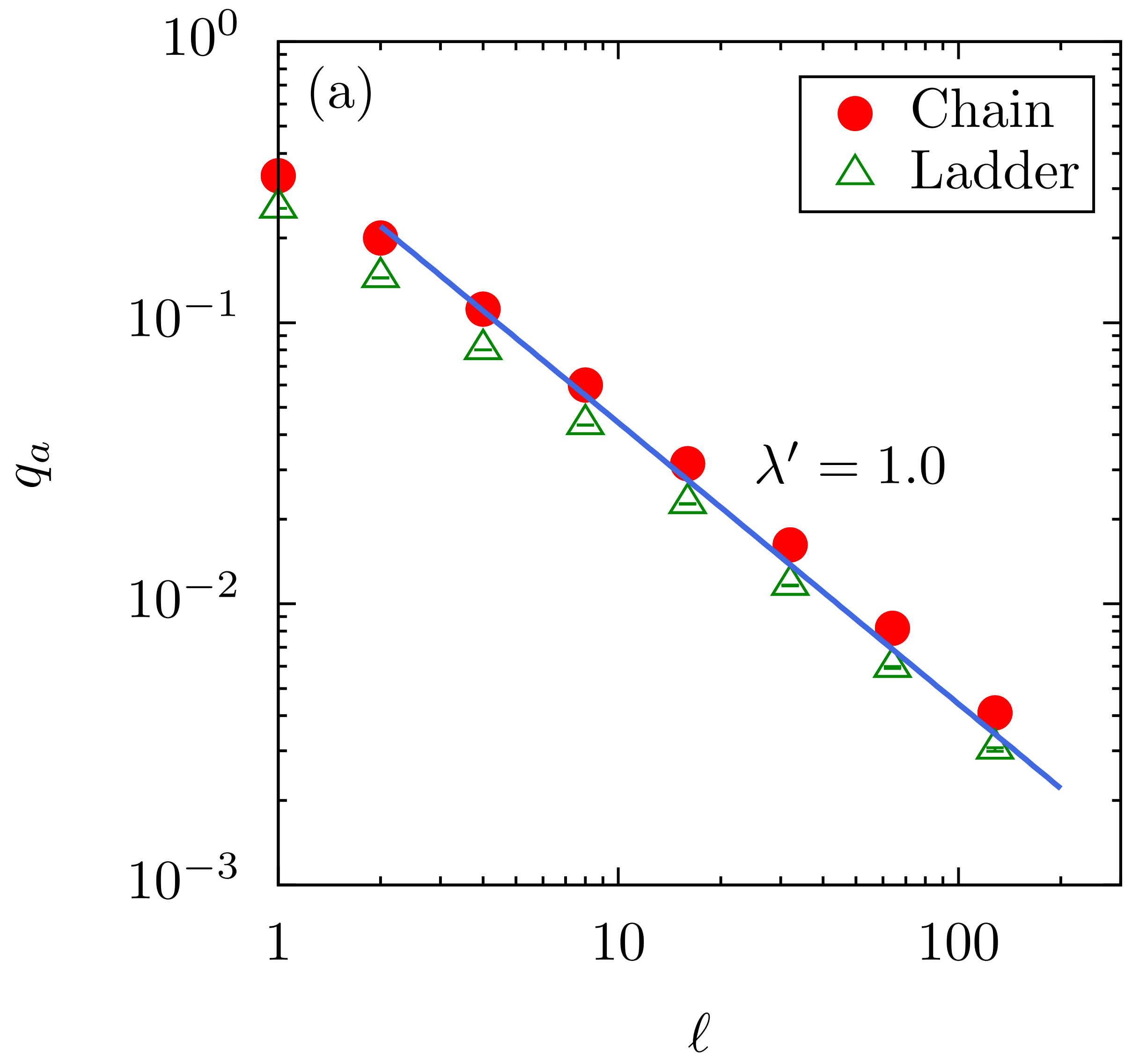
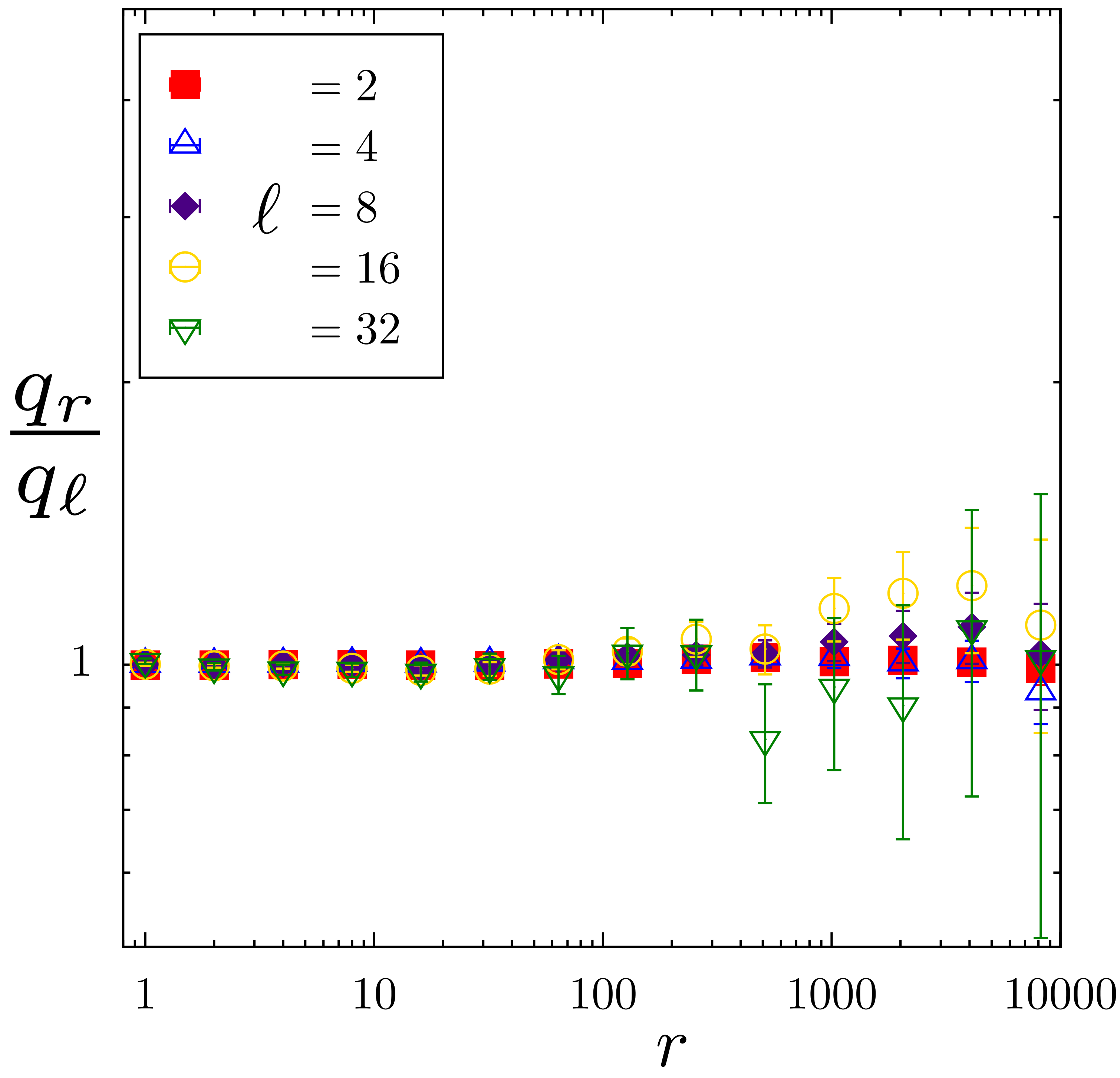
Why?

1D aging



$$q_a \sim \ell^{-1.0}$$

1D recovery



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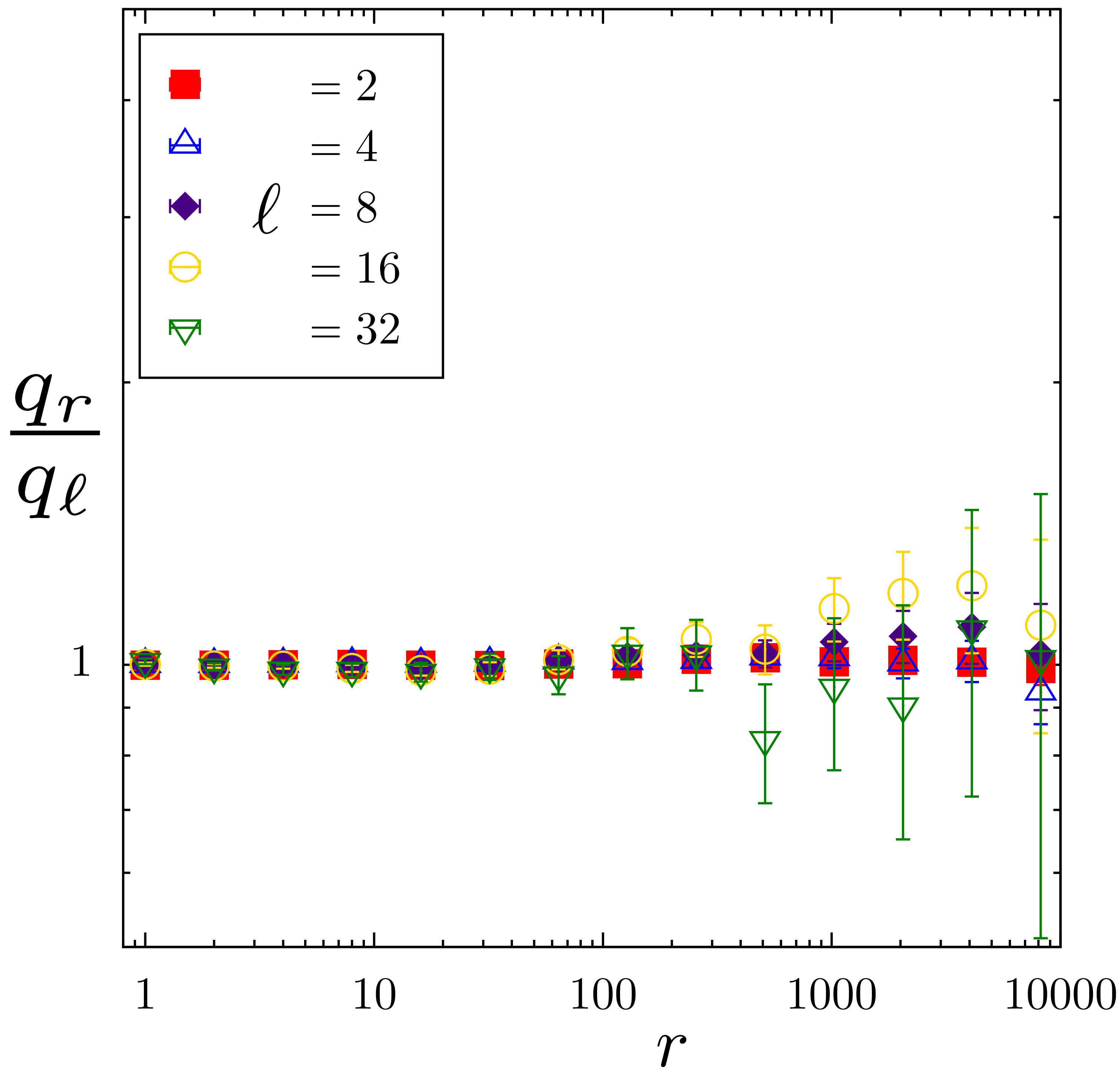
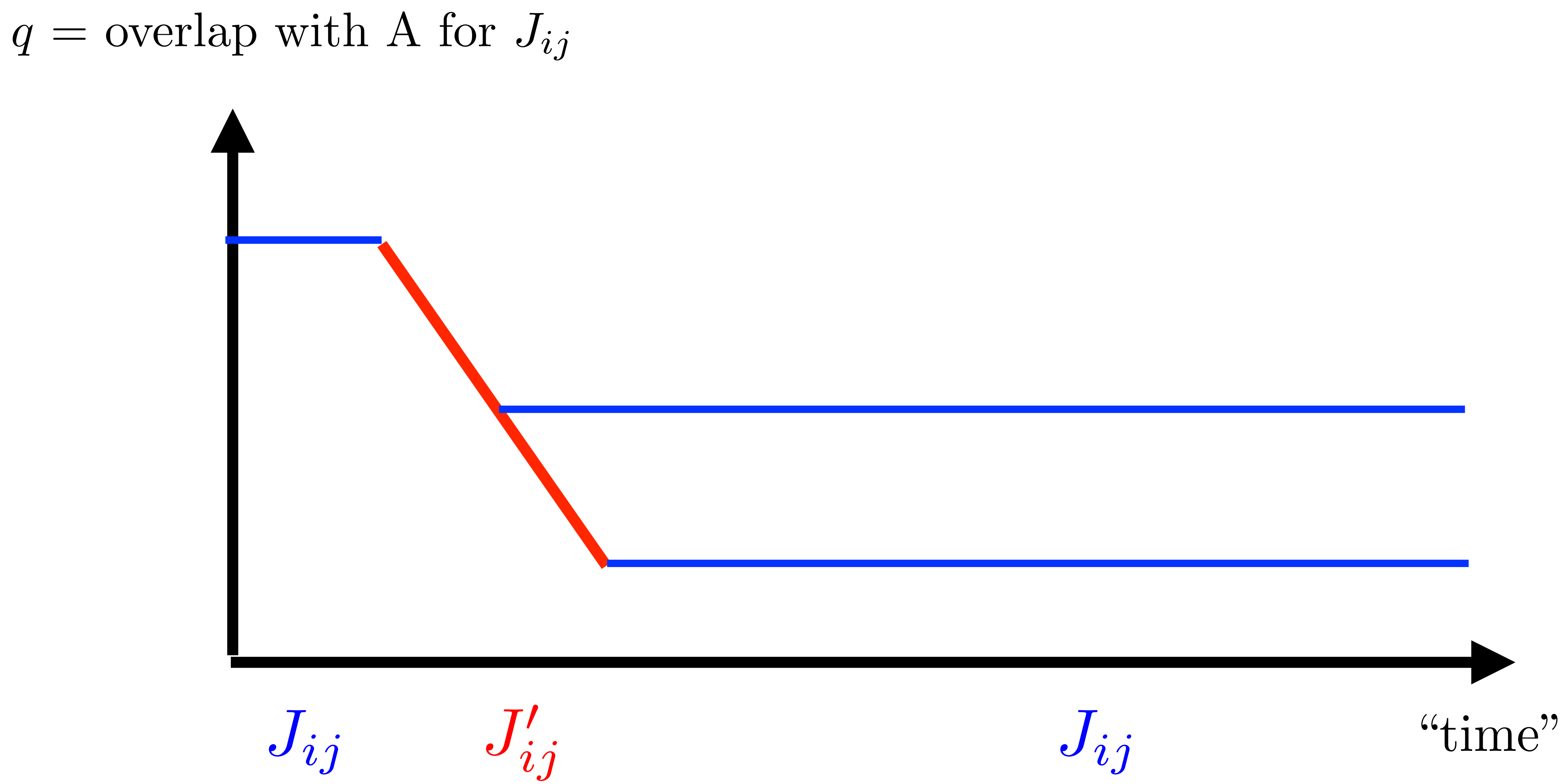


Can prove.

Coarsening while maintaining A to $\overline{A}$ ratio.

Flips to A more frequently, but being "wrong" causes more damage.

$$d = 1$$



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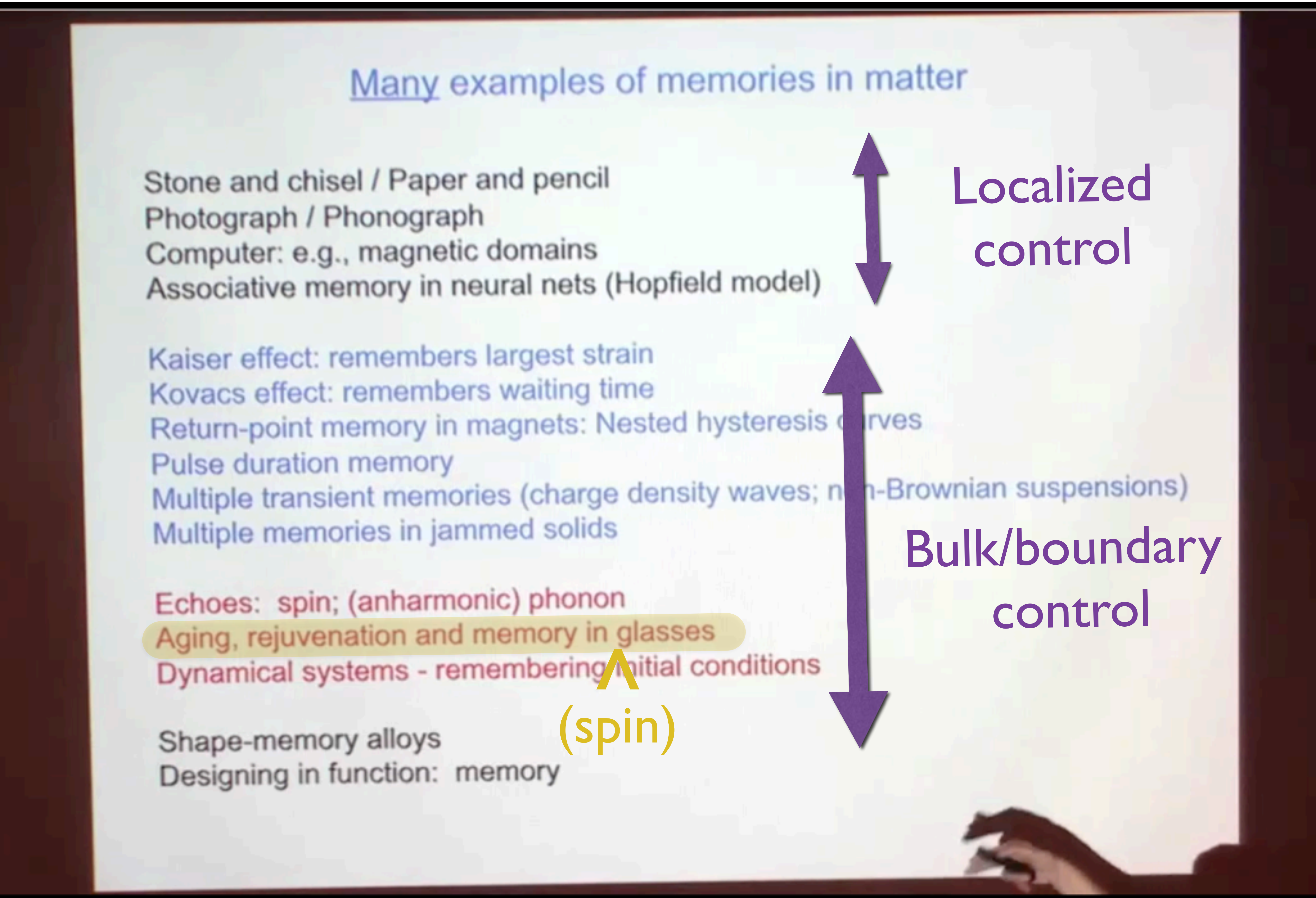

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