Janus, an FPGA-Based System for High-Performance Scientific Computing

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Computer Simulations on GPU
Mainz, June 1, 2011

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Esquema

Spin glasses

- Spin glasses: random, mixed-interacting, magnetic system. Random, yet cooperative, freezing of spins at a temperature T_c.
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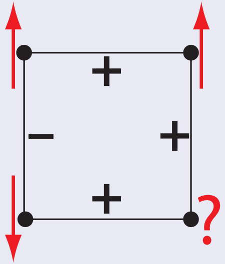
- Quenched and random interactions: $J_{ij} = \pm 1$ with 50% probability.



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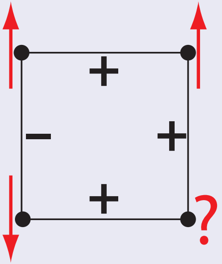

- Experimental system:
  - Dilute magnetic atoms in non-magnetic material (e.g. Mn in Cu).
  - RKKY interaction: sign oscillates with distance $\Rightarrow$ frustration.

Free-energy landscapes and slow dynamics

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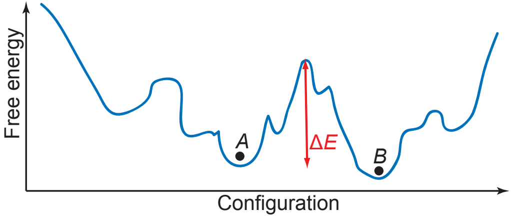

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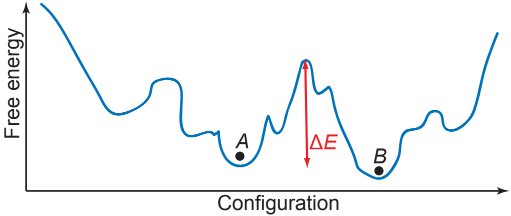

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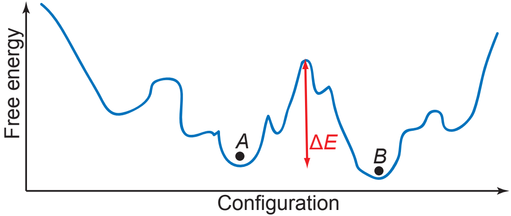

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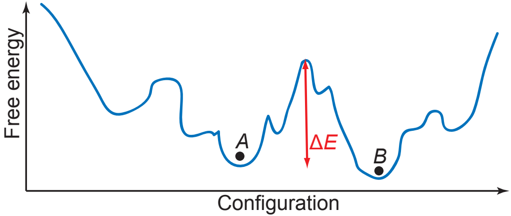

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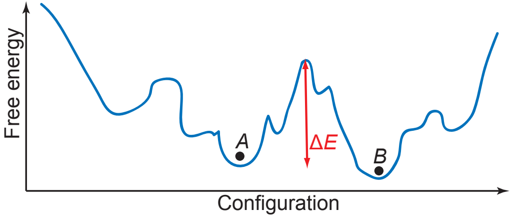

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- Spin glasses are paradigmatic problems:
  - Amenable to precise experimental investigation
  - Simple theoretical models are faithful to the physics

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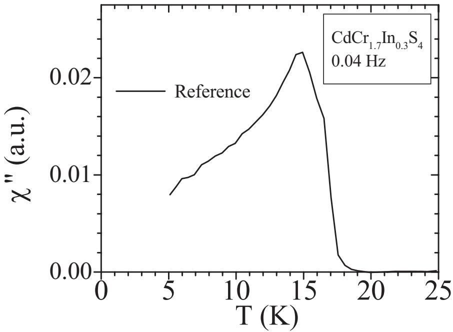
- Example: memory effects [Jonason et al., PRL **81**, 3243 (1998)]



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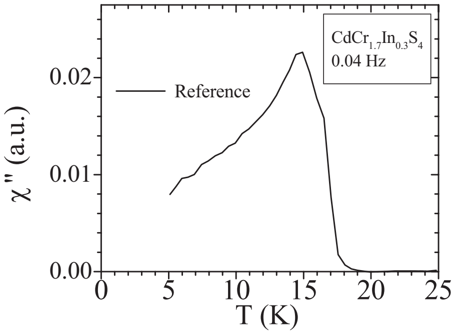

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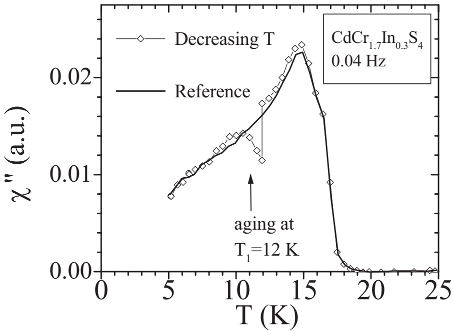

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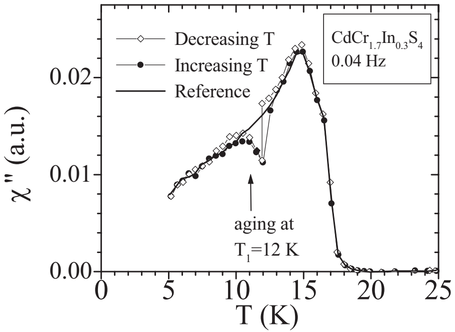

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4. Reheat without stopping. The system has memory of the aging.

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- Problem 2:
  - We need the system to remain off-equilibrium for very long times $\Rightarrow$ simulate very large lattices.

Optimisation possibilities (I)

- Since we want to emulate the physical evolution, we cannot use optimised dynamics.
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- For each site in the lattice, we can fit the corresponding spins from 64–128 samples in a single integer.
- Update them all at the same time, using logical operations.
- Only one random number per site, shared for all samples.

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  - However, does not reduce wall-clock time.
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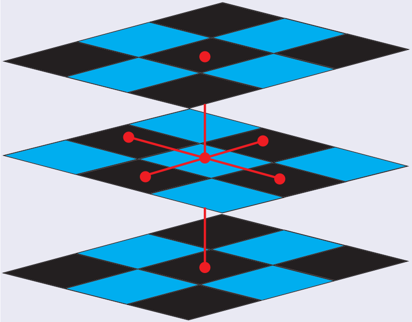

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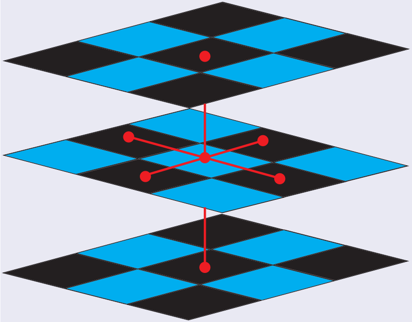

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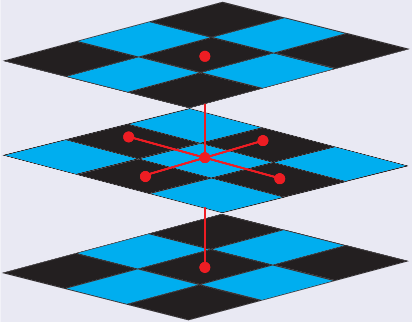

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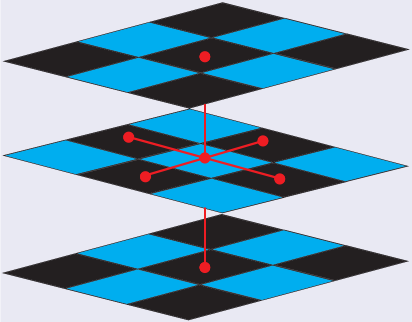

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- We need a different kind of architecture

Esquema

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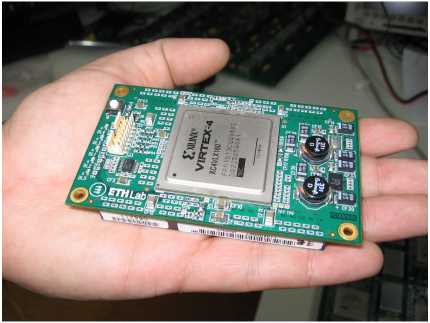

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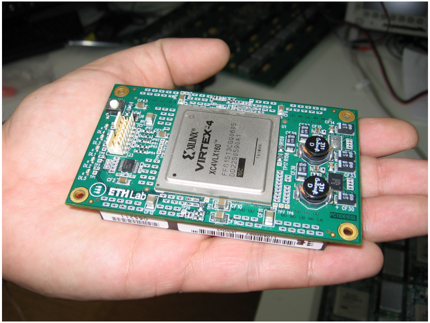

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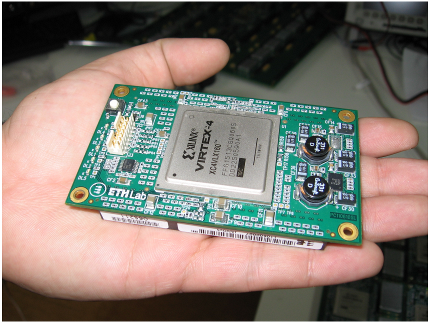

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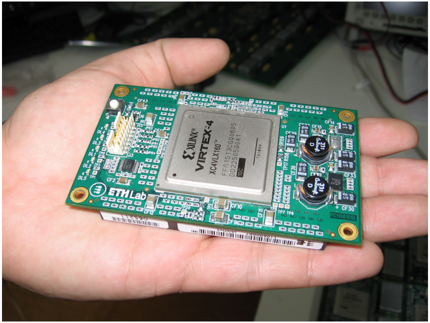

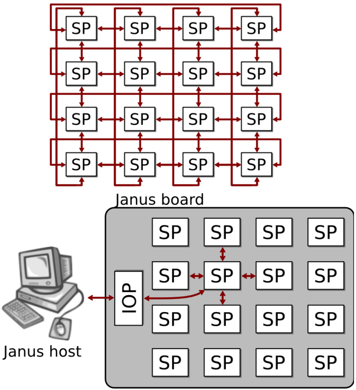

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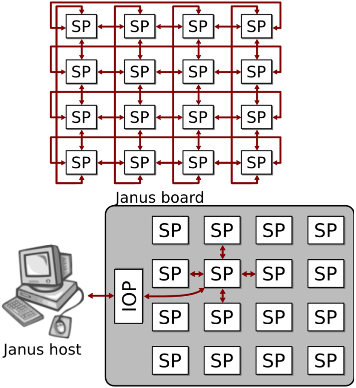
- Data links among nearest neighbours

The Janus machine



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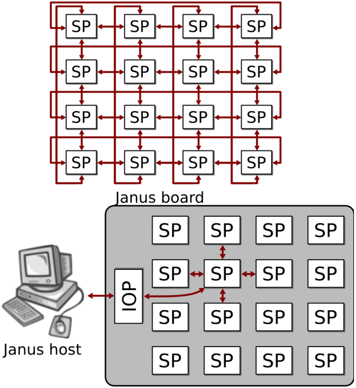

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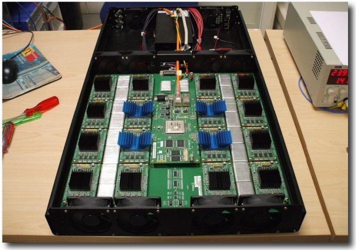

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- A total of 16 boards (256 SPs) in a Janus rack

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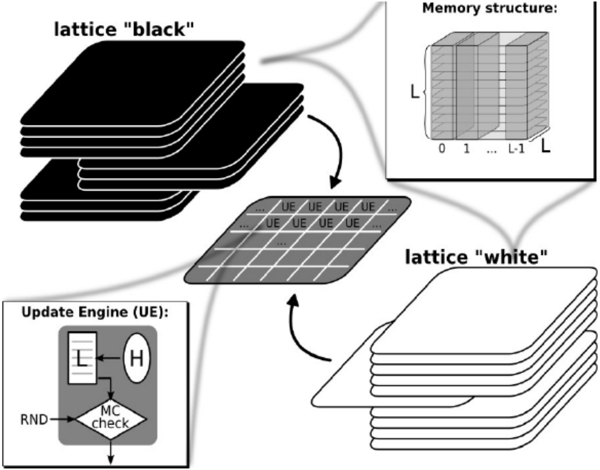
- Pipelineable to one spin update per clock cycle per UE.
- Each SP has enough memory for systems of linear size $L = 88$.

Implementation, general picture

An overview



Random numbers (I)

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- For each RN: sum two and XOR with a third.
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  the computed sum filling the empty position.
- A straightforward implementation produces a RN per step (for each wheel that we maintain).
- We need more
- Solution: implement it through logic (not memory) blocks.

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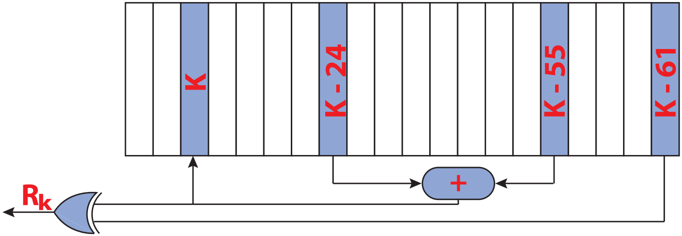

Random numbers (II)

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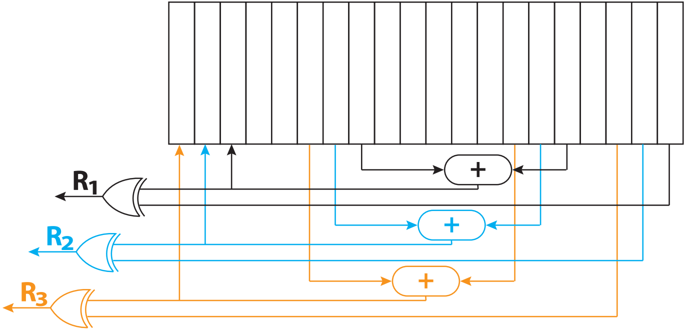

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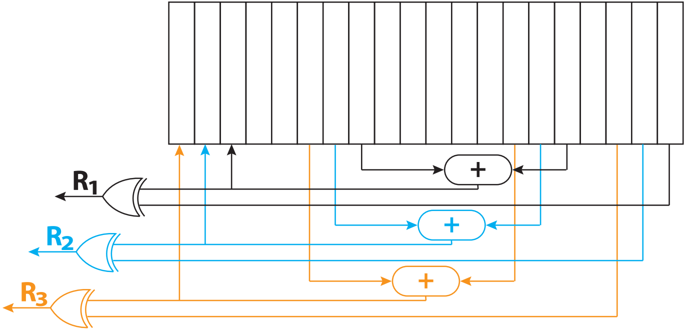

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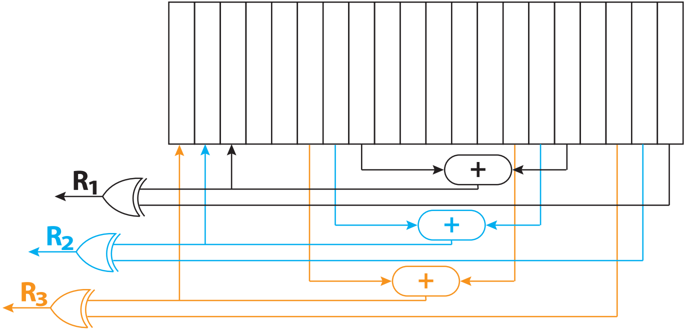

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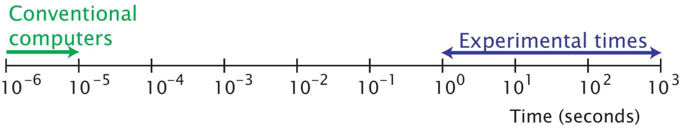

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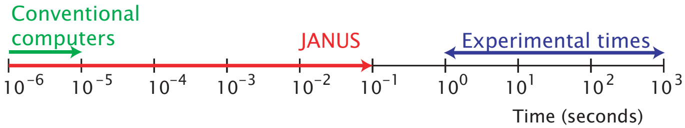

Esquema

The spin correlation function

- The spin correlation function measures the memory at time $t + t_\mathrm{w}$ of the configuration at t_w:

$$C(t, t_\mathrm{w}) = \overline{L^{-3} \sum_{\boldsymbol{x}} \sigma_{\boldsymbol{x}}^{t+t_\mathrm{w}} \sigma_{\boldsymbol{x}}^{t_\mathrm{w}}} \quad \Longrightarrow \quad \begin{cases} C = 1 & \longrightarrow \text{ same config.} \\ C = 0 & \longrightarrow \text{ no memory.} \end{cases}$$

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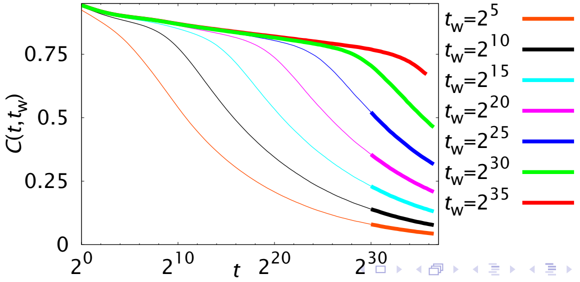

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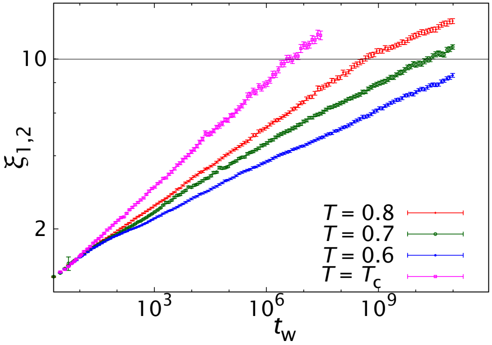

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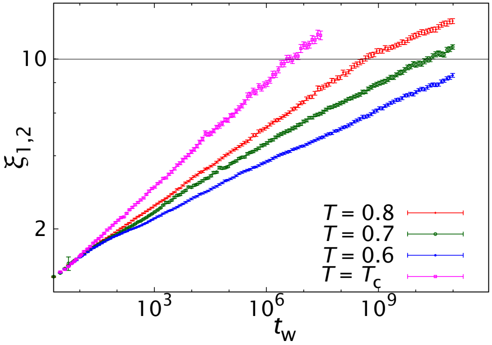

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Summary of Janus' physics work

Non-equilibrium spin-glass dynamics

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The equilibrium spin-glass phase

- We have studied the low-temperature spin-glass phase
- Parallel tempering with Janus
- Equilibrate 10^3 up to $L = 32$ and down to $T = 0.64T_c$.
- A total of over 10^{21} spin updates
- We find evidence in favour of the RSB picture,
  at least for experimentally relevant scales.
- PRL **105**, 177202 (2010), JSTAT **(2010)** P06026.

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Critical behaviour of the Potts glass

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Work in progress

- We are currently studying the dynamics and critical point of the Edwards-Anderson spin-glass in $D = 3, 4$, with an applied magnetic field.

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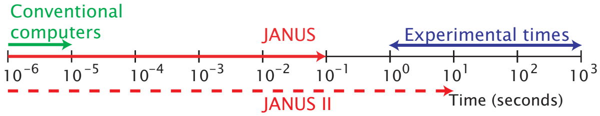

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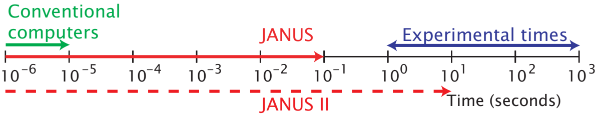

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- Also very efficient for critical-point studies, where the simulations are shorter, but cheaper alternatives (GPUs) are competitive there.
- Janus is very energy-efficient: the whole rack needs only ≈ 11 kW and is capable of ≈ 8.75 Gops/W.