The standard multiplicative coalescent revisited

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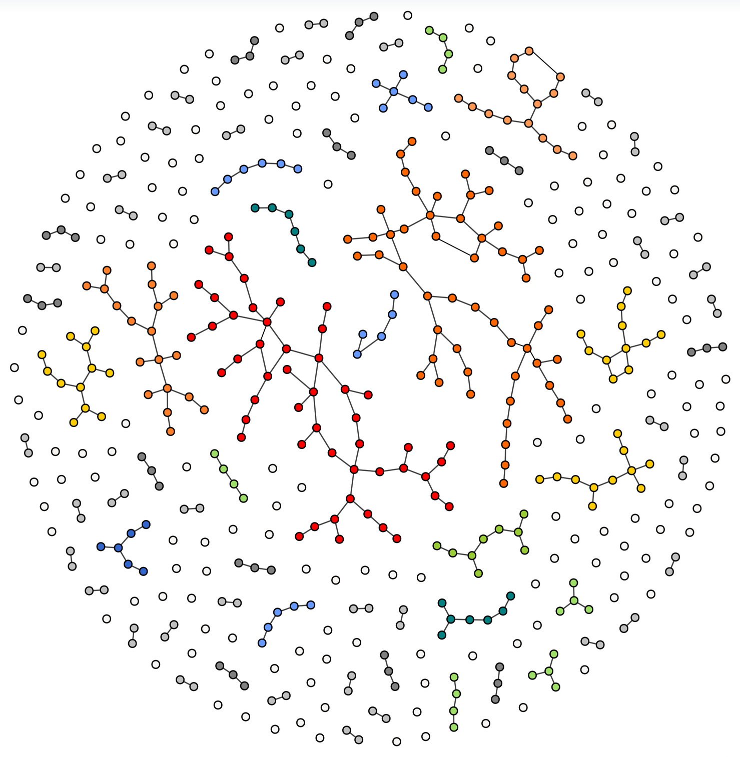
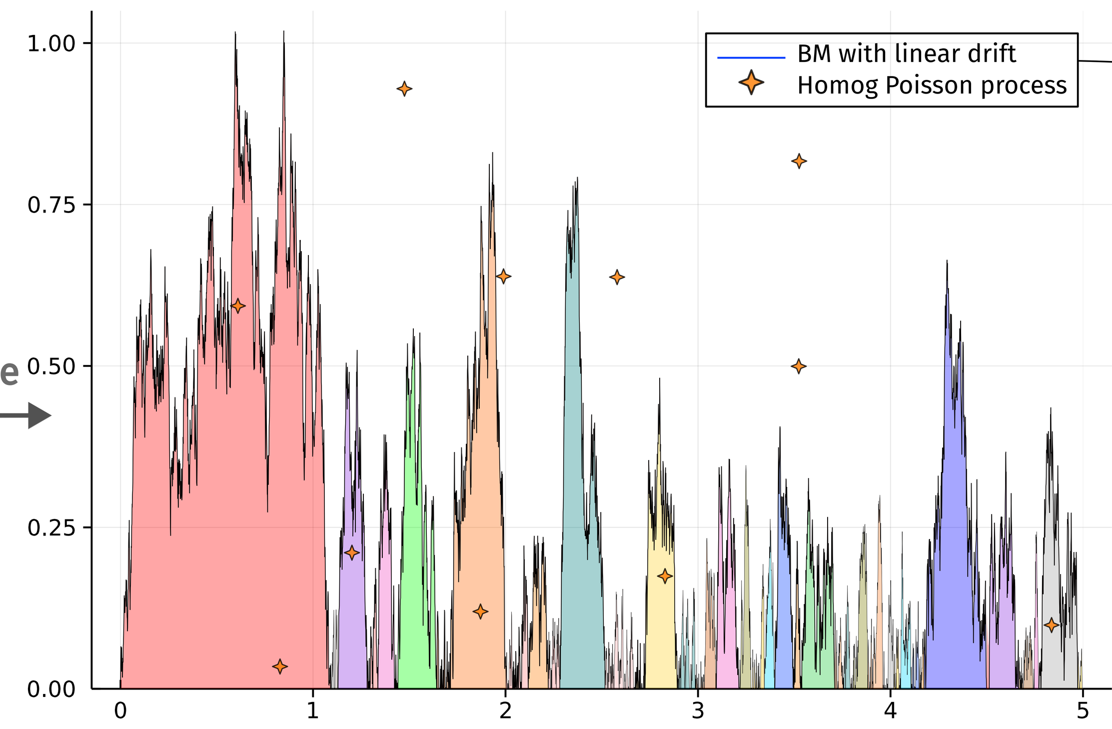
Main result

Erdös-Rényi random graph :

- n vertices
- each edge exists with probability $\frac{1}{n} + \frac{t}{n^{4/3}}$



convergence in law



Brownian motion $(W(s), s \geq 0)$

BM with linear drift $W^t(s) := W(s) - \frac{1}{2}s^2 + t \cdot s$

Reflected BM with linear drift $B^t(s) := W^t(s) - \inf_{0 \leq u \leq s} W^t(u)$

($n^{-2/3}$ size of the connected components, number of surplus edges) (length of the excursions, number of marks below the curve)

Erdös-Rényi (1960), Bollobas (1985), Aldous (1997)

size of the largest component

$\Theta(\ln n)$ $\Theta(n)$

0 $\frac{1}{n}$ $\Theta(n^{2/3})$ within this time window all the connected components are of the same order

$t_n = \frac{1}{n} + \frac{t}{n^{4/3}}$ with $t \in \mathbb{R}$

a simulation

$\left(\mathbb{MG}^{(n)}(t), t \geq 0\right)$ multi-graph-valued Markov chain

- each vertex has size $n^{-2/3}$
- $\#(i \longrightarrow j) = N_{\{i,j\}}(t)$ Poisson process with rate $n^{4/3}/2$

directed edge

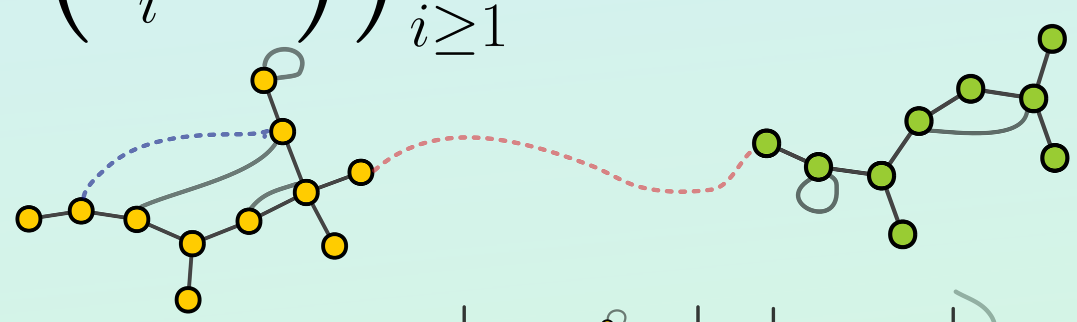
$\mathbb{MG}^{(n)}(t) \rightsquigarrow$ Erdös-Rényi $\left(n, 1 - \mathrm{e}^{-n^{4/3}\, t}\right)$

critical time : $n^{1/3} + t$

$C_i^{(n)}(t)$ i-th largest connected component of $\mathbb{MG}^{(n)}(t)$

$|C_i^{(n)}(t)|$ size and $\mathrm{SP}\left(C_i^{(n)}(t)\right)$ number of surplus edges

$\left(|C_i^{(n)}(t)|, \mathrm{SP}\left(C_i^{(n)}(t)\right)\right)_{i \geq 1}$ Markov process with dynamic



coalescence jump: with rate $|\cdot| \cdot |\cdot|$

surplus jump: with rate $|\cdot|^2/2$

augmented multiplicative coalescent (AMC)

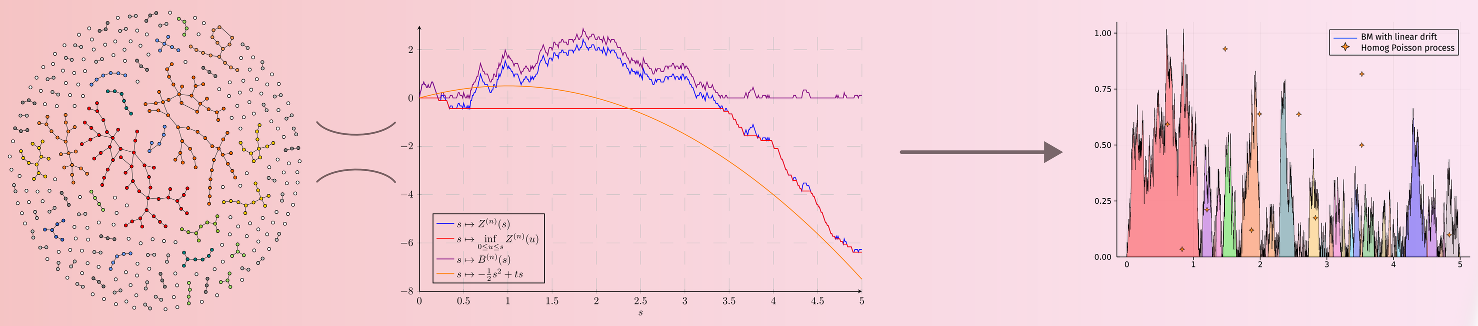
Space $\left\{(x_i, n_i)_{i \geq 1} \in l^2_{\searrow} \times \mathbb{N}^\infty : \sum_{i=1}^{\infty} x_i n_i < \infty \text{ and } n_i = 0 \text{ whenever } x_i = 0,\ i \geq 1\right\}$

size of the i-th connected component; number of surplus edges in the i-th connected component

Metric $\mathrm{d}_{\mathbb{U}}((\boldsymbol{x}, \boldsymbol{n}), (\boldsymbol{x}', \boldsymbol{n}')) = \left(\sum_{i=1}^{\infty} (x_i - x_i')^2\right)^{1/2} + \sum_{i=1}^{\infty} |x_i \cdot n_i - x_i' \cdot n_i'|$

(making a process with the AMC dynamic a Feller process)

Proof sketch



Main difficulty: control of the tail $\lim_{\delta \to 0} \limsup_{n} \mathbb{E}\left[\sum_{i \geq 1} X_i^{(n)} \cdot N_i^{(n)} \cdot \mathbf{1}_{\{X_i^{(n)} < \delta\}}\right] = 0$

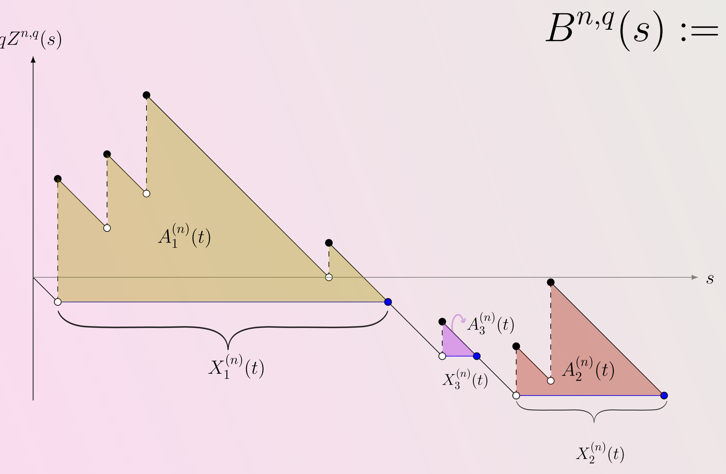
Methods

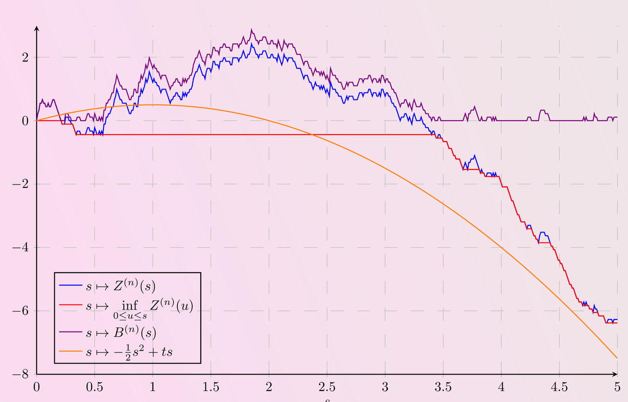
- bringing the tail to the beginning: $\mathbb{E}\left[\sum_{i \geq 1} X_i^{(n)} \cdot N_i^{(n)} \cdot \mathbf{1}_{\{X_i^{(n)} < \delta\}}\right] = n^{1/3} \cdot \mathbb{E}\left[\mathrm{SP}(\mathcal{C}(V_n)) \mathbf{1}_{\{|\mathcal{C}(V_n)| < \delta\}}\right]$ randomly chosen vertex
- encoding: $\mathbb{E}\left[\mathrm{SP}(\mathcal{C}(V_n)) \mathbf{1}_{\{|\mathcal{C}(V_n)| < \delta\}}\right] = \mathbb{E}\left[\int_{\text{First excursion}} B^{(n)}(s)\, \mathrm{d}s \cdot \mathbf{1}_{\{|\text{First excursion}| < \delta\}}\right]$
- controling the expectd area below the curve: $\leq \delta\, n^{-1/3}$
- counting the multi-edges and self-loop

Simultaneous breadth-first walk

$$Z^{n,q}(s) = \sum_{i=1}^{n} \frac{1}{n^{2/3}} \mathbf{1}_{(\xi_i/q \leq\ s)} - s, \text{ where } \xi_i \sim \exp(\text{rate } = \frac{1}{n^{2/3}})$$

$$B^{n,q}(s) := Z^{n,q}(s) - \inf_{u \leq s} Z^{n,q}(u)$$





Encoding the AMC

$X_i^{(n)}(t)$ size of the i-th excursion

$N_i^{(n)}(t) = \underbrace{\mathrm{Poisson}(A_i^{(n)}(t))}_{\text{area below the curve under the i-th excursion}}$

Theorem (C. and Limic 2023+)
$\left(X_i^{(n)}(t), N_i^{(n)}(t)\right)_{i \geq 1}$ is equal in law to $\left(|C_i^{(n)}(t)|, \mathrm{SP}\left(C_i^{(n)}(t)\right)\right)_{i \geq 1}$

$$q_n(t) = n^{1/3} + t$$

Theorem (Limic 2019)
$q_n(t) Z^{n, q_n(t)}(s)$ converges in distribution towards $W^t(s)$

$\mathcal{X}_i(t)$ size of the i-th excursion of $W^t(s)$ $\quad \mathcal{N}_i(t) = \underbrace{\mathrm{Poisson}(\mathcal{A}_i(t))}_{\text{area below the curve under the i-th excursion of } W^t(s)}$

We need to prove: $\mathrm{d}_{\mathbb{U}}\left((X_i^{(n)}, N_i^{(n)})_{i \geq 1}, (\mathcal{X}_i(t), \mathcal{N}_i(t))_{i \geq 1}\right) \xrightarrow[n \to \infty]{\mathbb{P}} 0$

Bibliography:

- Aldous, *Brownian excursions, critical random graphs and the multiplicative coalescent* (1997)
- Bhamidi, Budhiraja and Wang, *The augmented multiplicative coalescent, bounded size rules and critical dynamics of random graphs* (2014)
- Broutin and Marckert, *A new encoding of coalescent processes: applications to the additive and multiplicative cases* (2016)
- Corujo and Limic, *A dynamical approach to spanning and surplus edges of random graphs*, arXiv: 2305.04716
- Limic, *The eternal multiplicative coalescent encoding via excursions of Lévy-type processes* (2019)

Read this poster online

This poster is based on the preprints:
Corujo and Limic *The standard augmented multiplicative coalescent revisited* (2023)

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