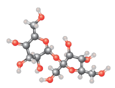
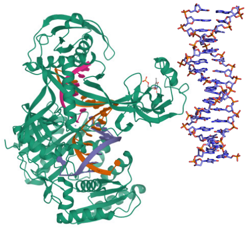
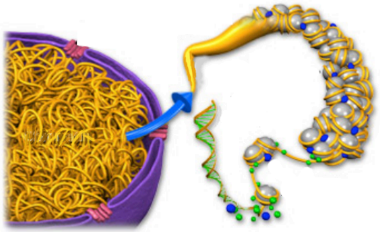
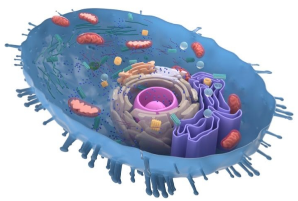
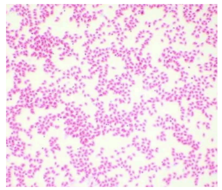
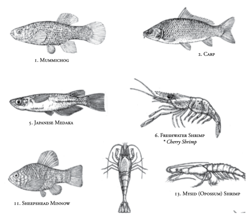
Biophys: biological applications of the methods of theoretical physics

Tiana's group

Cosentino-Lagomarsino's group


10^{-10} m	10^{-8} m	10^{-7} m	10^{-5} m	10^{-3} m	1 m	10^{2} m
10^{-12} s	10^{-6} s	1 s	10^{5} s			10^{8} s
10^{-2} eV			10^{2} eV			10^{19} eV

(classical physics: complex systems & statistical mechanics)

INFN

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Statistical Mechanics

E. Marchi and G. Tiana, **Length-dependent residence time of contacts in simple polymeric models**, Phys. Rev. E (2025)

F. Borando and G. Tiana, **Effective model of protein-mediated interactions in chromatin** , Phys. Rev. E (2024)

...

Biological/medical applications

Cardamone *et al.* C**hromatin landscape at cis-regulatory elements orchestrates cell fate decisions in early embryogenesis** , Nature Comm. (2025)

Barberis et al., **A rationale for the poor response to alectinib in a patient with adenocarcinoma of the lung harbouring a STRN-ALK fusion by Artificial Intelligence and molecular modelling**. Transl. Lung Canc. Res. (2024)

Mach et al. **Live-cell imaging and physical modeling reveal control of chromosome folding dynamics by cohesin and CTCF** , Nature Genetics (2022)

...

Machine learning

A. Zambon, R. Zecchina and G. Tiana, **Structure of the space of folding protein sequences defined by large language models**, Phys. Biol. (2024)

A. Zambon, E. M. Malatesta, G. Tiana and R. Zecchina, **Sampling the space of solutions of an artificial neural network**, Phys. Rev E (in press)

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Statistical Mechanics

Chaboche et al. **A mean-field theory for predicting single polymer collapse induced by neutral crowders**, Soft Matter (2024)

...

Biological/medical applications

Grassi et al. **Heterogeneity and evolution of DNA mutation rates in microsatellite stable colorectal cancer,** Science Transl. Med. (2025)

Droghetti et al. **Incoherent feedback from coupled amino acids and ribosome pools generates damped oscillations in growing *E. coli*** (2025)

Iuliani et al. **Direct single-cell observation of a key *Escherichia coli* cell-cycle oscillator**, Science Adv. (2024)

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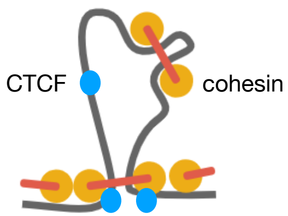
Example: effective interactions in DNA

1) Loop extrusion ⋯⋯⋯→ stochastic processes

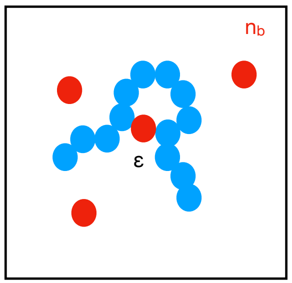


$$\frac{dp_{i,j}}{dt} = k_{\text{on}}\delta_{|i-j|,1} - k_{\text{off}}p_{i,j} + k\tilde{\delta}^{-}_{i+1}p_{i+1,j} - k\tilde{\delta}^{-}_{i}p_{i,j} + k\tilde{\delta}^{+}_{j-1}p_{i,j-1} - k\tilde{\delta}^{-}_{j}p_{i,j},$$

$$\longrightarrow \quad E = -T\sum_{n<m}\log\left[\binom{n+m+1}{m}\,{}_2F_1(1,1-n,1+m,-1)\left(\frac{k}{k_{off}+2k}\right)^{m+n-1}\right]\Delta(|\mathbf{R}_n - \mathbf{R}_m|)$$

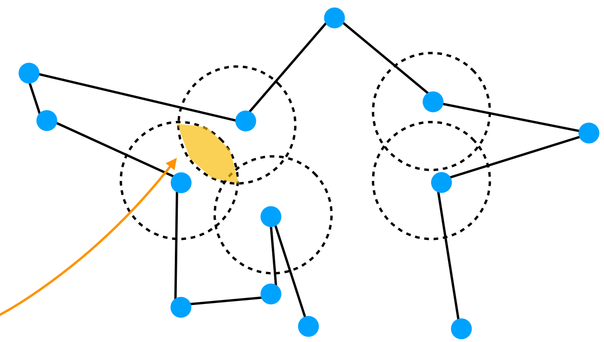
- obtain an effective model (...simpler)
- explains the power law in contact probability

2) Protein-mediated interactions



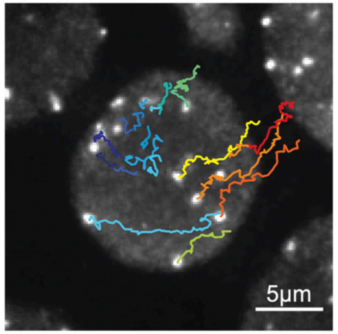
$$E(\mathbf{R}) = -Tn_b\log\left[V + \sum_k V_k(\mathbf{R})\left(e^{\beta\epsilon k} - 1\right)\right]$$

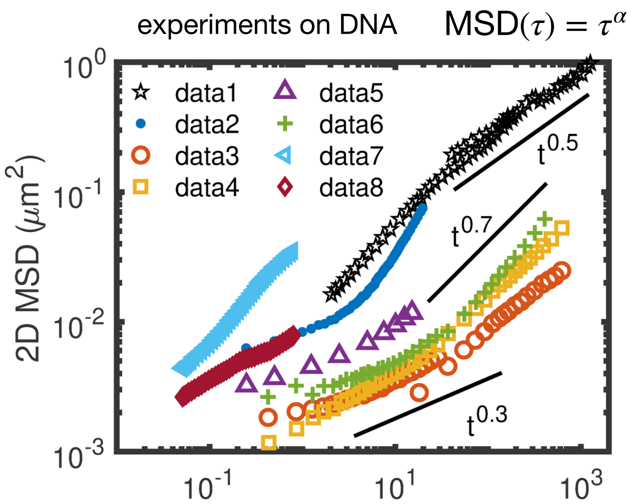
e.g., k=2



Example: subdiffusion

$$\text{MSD}(\tau) = \overline{[r(t+\tau) - r(t)]^2}$$





$$\frac{d\mathbf{r}_n}{dt} = \frac{k}{\gamma}(\mathbf{r}_{n+1} + \mathbf{r}_{n-1} - 2r_n) - \underbrace{\frac{k'}{\gamma}(\mathbf{r}_n - \mathbf{r}_{n+m})}_{\text{quenched links}} + \frac{1}{\gamma}\eta_n(t)$$

$$\overline{|\mathbf{r}(x,t)|^2} = \frac{3Dt}{N} + \underbrace{\sum_{p\neq 0}\left|\frac{D\tau_p}{N}[1 - e^{-t/\tau_p}]\right|}_{\equiv I(t)}$$

$$\tau_p \equiv \frac{N^2\gamma}{\pi k p^2 + \underbrace{N^2 k'[1 - \cos(\pi pm/2N)]}_{\text{quenched links}}}$$

$$\begin{aligned} E_x[I_x(t)] &= \int_0^2 dx\, P(x) I_x(t) \\ &= \text{erf}(\sqrt{2t}) + t^{\beta/2}[\Gamma(1/2 - \beta/2, 2t) \\ &\quad - \Gamma(1/2 - \beta/2)] \\ &\sim t^{\beta/2} \end{aligned}$$