



Universiteit
Leiden
The Netherlands

Dormancy in stochastic interacting systems

Nandan, S.

Citation

Nandan, S. (2023, May 11). *Dormancy in stochastic interacting systems*. Retrieved from <https://hdl.handle.net/1887/3608202>

Version: Publisher's Version

[Licence agreement concerning inclusion of doctoral](#)

License: [thesis in the Institutional Repository of the University of](#)
[Leiden](#)

Downloaded from: <https://hdl.handle.net/1887/3608202>

Note: To cite this publication please use the final published version (if applicable).

Dormancy in Stochastic Interacting Systems

Shubhamoy Nandan

Cover pages, part, and chapter openers: images obtained by taking screenshots of a simulation (available at <https://chainserver.pythonanywhere.com/hiv-dormancy>) made by the author of this thesis. The 3D model used in the simulation is of an HIV-cell which is known to exhibit dormancy (or *latency*) lasting up to 10 or 15 years.

The research in this thesis was supported by the Netherlands Organisation for Scientific Research through grant number TOP1.17.019.

Dormancy in Stochastic Interacting Systems

Proefschrift

ter verkrijging van
de graad van doctor aan de Universiteit Leiden,
op gezag van rector magnificus prof.dr.ir. H. Bijl,
volgens besluit van het college voor promoties
te verdedigen op donderdag 11 mei 2023
klokke 15:00 uur

door

Shubhamoy Nandan
geboren te Mogra, West Bengal, India
in 1995.

Promotores:

Prof.dr. W.Th.F. den Hollander

Prof.dr. F.H.J. Redig (Technische Universiteit Delft)

Prof.dr. C. Giardinà (Università degli studi di Modena e Reggio Emilia)

Promotiecommissie:

Prof.dr. H.J. Hupkes

Prof.dr. R.M.H. Merks

Prof.dr. A. Greven (Universität Erlangen-Nürnberg)

Prof.dr. N. Kurt (Universität Frankfurt)

Dr. E. Pulvirenti (Technische Universiteit Delft)

Contents

1	Introduction	1
§1.1	Introduction to Part I	2
§1.1.1	Bits and pieces of genetics	2
§1.1.2	Mathematics of evolution	3
§1.1.3	The Moran model with seed-bank	11
§1.1.4	Spatially inhomogeneous Moran model with seed-banks	15
§1.1.5	Summary of Part I	19
§1.2	Introduction to Part II	24
§1.2.1	Hydrodynamic scaling limit	25
§1.2.2	Non-equilibrium steady state	29
§1.2.3	Summary of Part II	32
§1.3	Further research	37
§1.4	Outline of the thesis	39
I	Spatially inhomogeneous populations with seed-bank	43
<hr/>		
2	Spatially inhomogeneous populations with seed-bank: duality, existence, equilibrium	45
§2.1	Background, motivation and outline	46
§2.2	Main theorems	47
§2.2.1	Quick definition of the multi-colony system	48
§2.2.2	Well-posedness and duality	49
§2.2.3	Equilibrium: coexistence versus clustering	50
§2.3	Single-colony model and basic theorems	51
§2.3.1	Definition: resampling and exchange	51
§2.3.2	Duality and equilibrium	52
§2.3.3	Interacting seed-bank coalescent	54
§2.4	Multi-colony model and basic theorems	56
§2.4.1	Definition: resampling, exchange and migration	57
§2.4.2	Spatially interacting seed-bank coalescent	59
§2.4.3	Well-posedness and equilibrium	62
§2.4.4	Clustering criterion	63
§2.5	Proofs: duality and equilibrium for the single-colony model	64

§2.5.1	Duality and change of representation	64
§2.5.2	Equilibrium	67
§2.6	Proofs: duality and well-posedness for the multi-colony model	69
§2.6.1	Uniqueness of dual	69
§2.6.2	Duality relation	71
§2.6.3	Well-posedness	77
§2.7	Proofs: equilibrium and clustering criterion for the multi-colony model	80
§2.7.1	Convergence to equilibrium	80
§2.7.2	Genetic variability (heterozygosity)	81
§2.7.3	Dual: single particle	82
§2.7.4	Dual: two particles	84
§2.7.5	Proof of clustering criterion	86
3	Spatially inhomogeneous populations with seed-bank: clustering regime	91
§3.1	Introduction	92
§3.2	Main theorems	92
§3.2.1	Preliminaries: assumption and notations	93
§3.2.2	Clustering versus coexistence	93
§3.3	Dual processes: comparison between different systems	96
§3.3.1	Two-particle dual and auxiliary duals	96
§3.3.2	Comparison between interacting duals	100
§3.3.3	Comparison with non-interacting dual	104
§3.3.4	Conclusion	106
§3.4	Proofs: clustering criterion and clustering regime	110
§3.4.1	Proof of clustering criterion	110
§3.4.2	Independent particle system and clustering regime.	110
§3.5	Discussion	116
4	Spatial populations with seed-banks in random environment	119
§4.1	Introduction	120
§4.2	Main theorems	121
§4.2.1	Recollection of previous results and basic notations	121
§4.2.2	Clustering in a fixed environment	122
§4.2.3	Clustering in random environment	125
§4.2.4	Discussion	127
§4.3	Single-particle dual in random environment	129
§4.3.1	Subordinate Markov chain and auxiliary environment process .	130
§4.3.2	Stationary environment process and weak convergence	133
§4.3.3	Transference of convergence: discrete to continuous	138
§4.4	Proof of main theorems	140
§4.4.1	Preliminaries: consistency of dual process	140
§4.4.2	Proofs: clustering in fixed and random environment	142
A	Appendix: Chapter 3	147

§A.1 Two-particle dual and alternative representation	147
§A.2 Completion of the proof of a theorem on the clustering regime	149
B Appendix: Chapter 4	155
§B.1 Proof of stationarity of environment process and law of large numbers	155
§B.1.1 Stationary distribution of environment process	155
§B.1.2 An application: strong law of large numbers	158
§B.2 Fundamental theorem of Markov chains	160
II Dormancy in switching interacting particle system	165
<hr/>	
5 Switching interacting particle systems	167
§5.1 Introduction	168
§5.1.1 Background and motivation	168
§5.1.2 Three models	170
§5.1.3 Duality and stationary measures	171
§5.1.4 Outline	173
§5.2 The hydrodynamic limit	174
§5.2.1 From microscopic to macroscopic	174
§5.2.2 Existence, uniqueness and representation of the solution	180
§5.3 The system with boundary reservoirs	183
§5.3.1 Model	184
§5.3.2 Duality	186
§5.3.3 Non-equilibrium stationary profile	188
§5.3.4 The stationary current	199
§5.3.5 Discussion: Fick's law and uphill diffusion	203
§5.3.6 The width of the boundary layer	208
C Appendix: Chapter 5	213
Bibliography	215
Samenvatting	227
Summary	230
Acknowledgements	233
Curriculum Vitae	235
Publications	236