

Computational Biology

Lecturers:

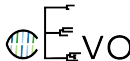
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James Munday & Marcus Overwater

Computational Evolution
Department of Biosystems Science and Engineering

HS 2023



Phylogenetics in
Action

Macroevolution

Epidemiology

Immunology

Developmental biology

Human migration

Language evolution

Cultural evolution

Finale

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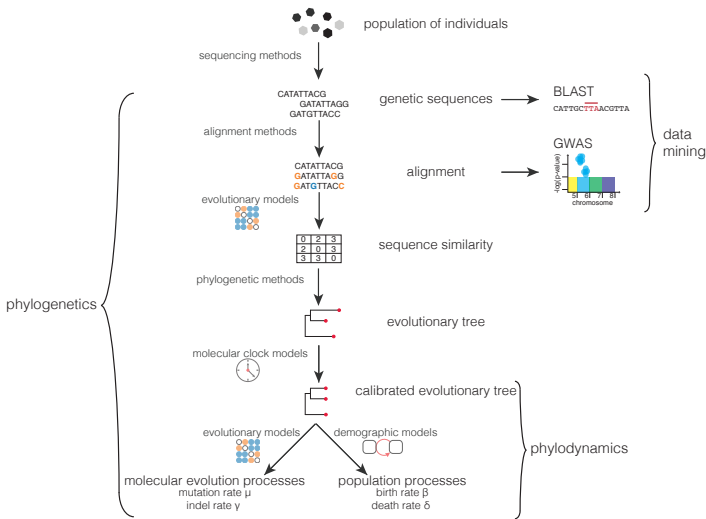
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Section 1

Phylogenetics in Action

Phylogenetics and Phylogenetics in Action

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Phylogenetics in Action

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References

individuals = species

- ▶ **(Molecular) Evolution**

Genetic information and morphology of species changes through time.

- ▶ **Phylogenetics**

Phylogeny displays species relationship.

- ▶ **Phylogenetics**

Population dynamics is the speciation and extinction process.

Examples: Dinosaurs; penguins.

individuals = infected hosts

- ▶ **Molecular Evolution**

Genetic information of pathogens changes through time.

- ▶ **Phylogenetics**

Phylogeny displays transmission history.

- ▶ **Phylodynamics**

Population dynamics is the transmission and recovery process.

Examples: Ebola, HCV, HIV, Zika. Today: SARS-CoV-2 work in our group

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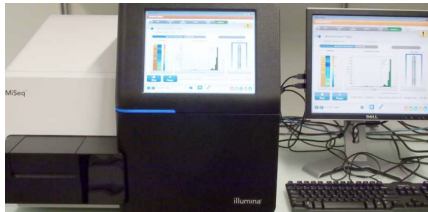
References

Swiss SARS-CoV-2 Sequencing Consortium (S3C)

Start in 03/2020 (ETHZ - Viollier AG); weekly sequencing up to now.

Until end of June 2020, 500 sequences from S3C and additionally 73 sequences from 7 other labs in CH.

Overall, > 70'000 published sequences (half of all CH sequences)



<https://bsse.ethz.ch/cevo/research/sars-cov-2/swiss-sars-cov-2-sequencing-consortium.html>

Members

Genomic and epidemiological analysis & overall coordination: Computational Evolution, D-BSSE, ETHZ, Chaoran Chen, Sarah Nadeau, Louis du Plessis.

Logistical & technical support:

- NEXUS, ETHZ, Franziska Singer, Matteo Carrara, Shuqing Yu.
- SIS, ETHZ, Uwe Schmitt.

Samples:

- Viollier AG, Andrea Salzmann, Henriette Kurth, Christiane Beckmann, Maurice Redondo, Olivier Kobel, Christoph Noppen.
- labor team w AG, Rebekka Pohl, Monika Bucher, Andreas Lindauer.

Bioinformatics: Computational Biology, D-BSSE, ETHZ ↗, Niko Beerenwinkel, Ivan Topolsky, Kim Philipp Jablonski, Lara Fuhrmann, David Dreifuss, Katharina Jahn, Pedro Ferreira.

Sequencing:

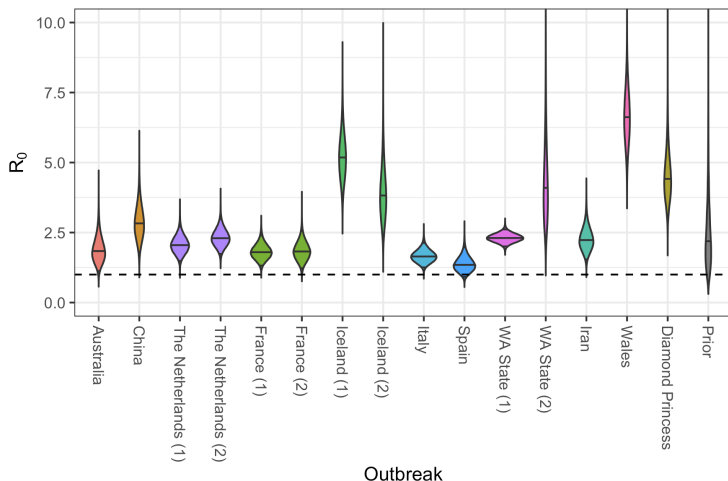
- Genomic Facility Basel, ETHZ, Christian Beisel, Rebecca Denes, Mirjam Feldkamp, Ina Nissen, Natascha Santacroce, Elodie Burcklen.
- Functional Genomic Center Zurich, ETHZ, Catharine Aquino, Andreia Cabral de Gouvea, Maria Domenica Moccia, Simon Grüter, Timothy Sykes, Lennart Opitz, Griffin White, Laura Neff, Doris Popovic, Andrea Patrignani, Jay Tracy, Ralph Schlapbach.
- Health 2030 Genome Center, Geneva, Keith Harshman, Ioannis Xenarios, Henri Pegeot, Lorenzo Cerutti, Deborah Penet.

Lead: Computational Evolution, D-BSSE, ETHZ, Tanja Stadler.

Former Members: Sophie Seidel, Noemie Santamaria de Souza, Susana Posada-Céspedes, Tobias Schär, Emmanouil Dermizakis.

What is the basic reproductive number of COVID-19?

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Vaughan et al. (2020, preprint)

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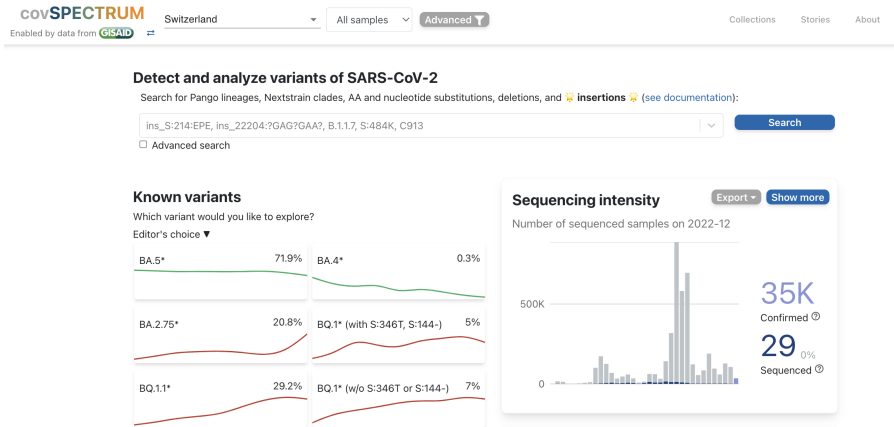
Language evolution

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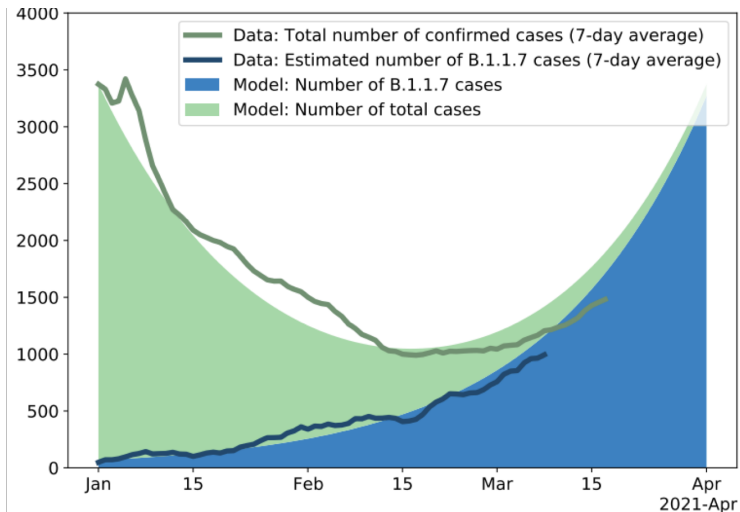
Frequencies of mutations and variants



cov-spectrum.org; Chen et al. (2021a, Bioinformatics)

Spread of Alpha projected in late 2020

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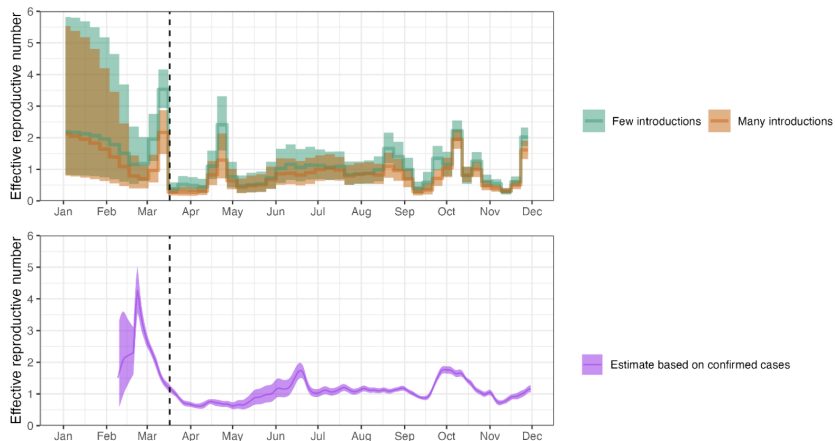
Cultural evolution

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Chen et al. (2021b, Epidemics)

Effective reproductive number through time in Switzerland based on sequences



Nadeau et al. (2022, Science Translational Medicine)

Impact of contact tracing quantified through phylodynamics

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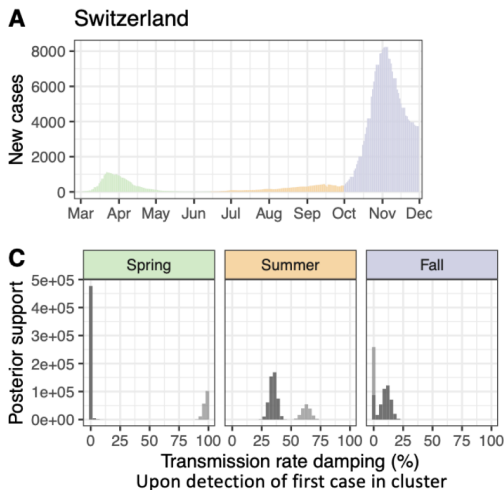
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Nadeau et al. (2022, Science Translational Medicine)

individuals = B cells

► **Molecular Evolution**

B cells change through time due to recombination and somatic hypermutation, as response to pathogen exposure.

► **Phylogenetics**

Phylogeny displays B cell evolution.

► **Phylogenetics**

Population dynamics is the B cell generation and loss process.

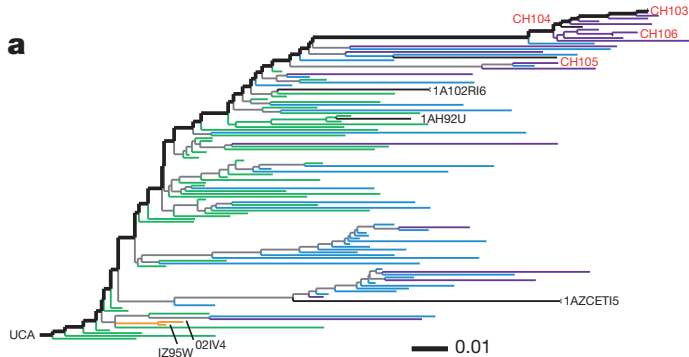


Figure adapted from Liao et al. 2013

Phylogeny of B-cells of an HIV infected individual. Future challenge is to investigate co-evolution of HIV and B-cell response.

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individuals = cells of a multicellular organism

► “Evolution”

Cell types change from stem cells to highly specialized cells.

► Phylogenetics

Phylogeny displays differentiation of cells through time.

► Phylodynamics

Population dynamics is the gain and loss of cell types.

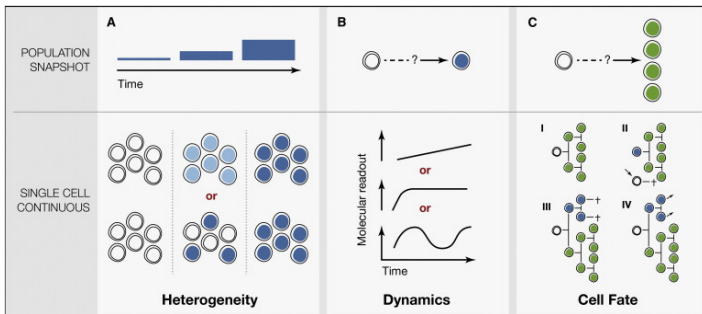


Figure adapted from Etzrodt et al. 2014

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individuals = human populations

- ▶ **Evolution:** Human genomes evolve slowly and recombination makes analysis very hard!
Solution: Study portions of the genome that do not recombine (Y chromosome + mtDNA)
- ▶ **Phylogenetics**
Phylogeny displays genetic relationships between human populations.
- ▶ **Phylogenetics**
Population dynamics is the migration process out of Africa.

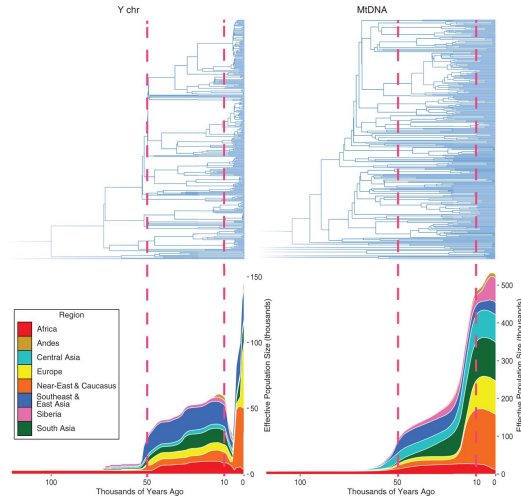


Figure adapted from Karmin et al. 2015

Bayesian skyline plot population dynamic inferences from Y chromosomes and mtDNA. (GTR substitution model.)

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individuals = languages

► Evolution

Words and letters change through time.

► Phylogenetics

Phylogeny displays language history.

► Phylodynamics

Population dynamics is the gain and loss of languages.

English	<i>all</i>	<i>sea</i>	<i>water</i>	<i>when</i>
German	<i>alle</i>	<i>see, meer</i>	<i>wasser</i>	<i>wann</i>
French	<i>tout</i>	<i>mer</i>	<i>eau</i>	<i>quand</i>
Italian	<i>tutto</i>	<i>mare</i>	<i>acqua</i>	<i>quando</i>
Greek	<i>pant</i>	<i>thalasa</i>	<i>nero</i>	<i>pote</i>
Hittite	<i>dapiya</i>	<i>aruna-</i>	<i>watar</i>	<i>kuwapi</i>

Figure adapted from <http://language.cs.auckland.ac.nz/what-we-did>

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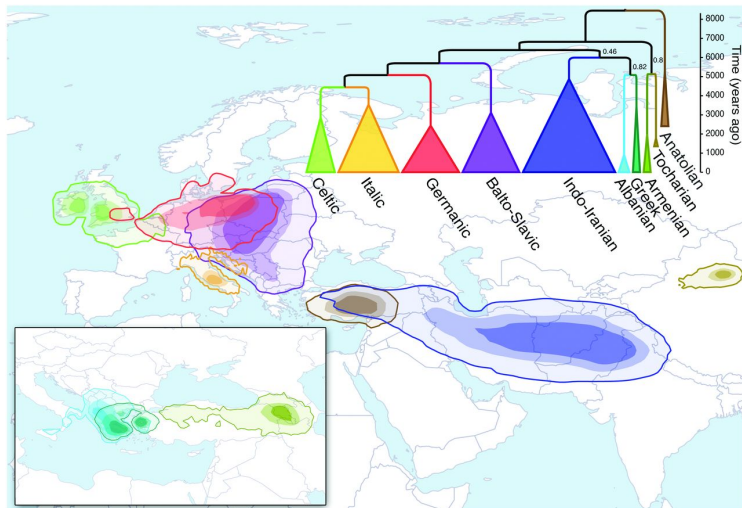


Figure adapted from Bouckaert et al. 2012

Mapping the origins and expansion of the Indo-European language family using a structured phylodynamic model.

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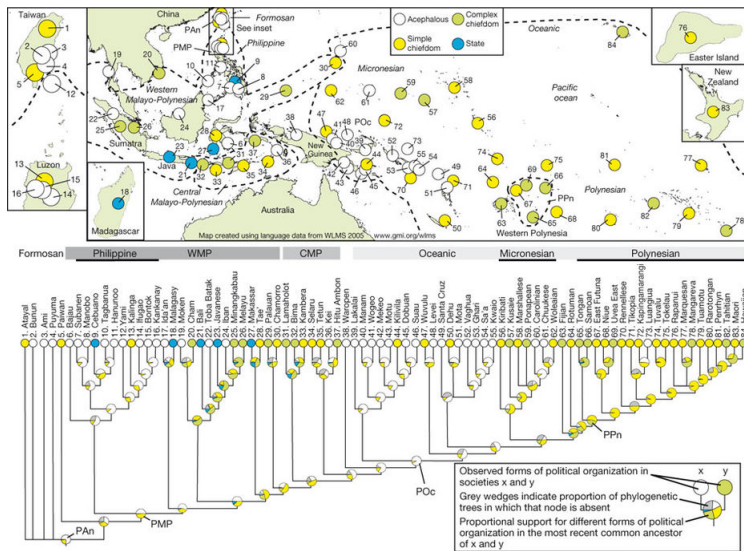
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individuals = human populations

- ▶ **Political systems:** How does the complexity of systems change over time Currie et al. 2010?
- ▶ **Religion:** Are social structures correlated with certain religious practices, such as ritual human sacrifice? Watts et al. 2016?

Cultural evolution: political systems



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Figure adapted from Currie et al. 2010

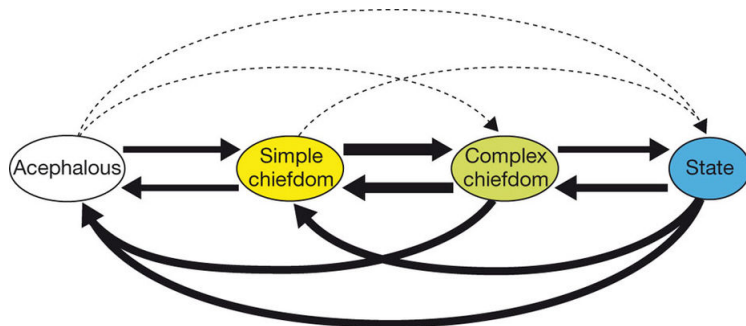


Figure adapted from Currie et al. 2010

Inferred rate of transitions between systems (thicker lines represent faster rates).

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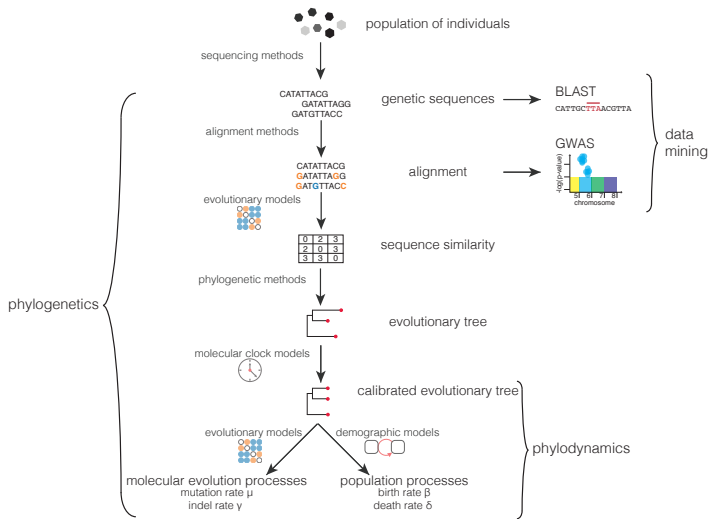
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Evolution of ritual human sacrifice (bottom) is correlated with evolution of social stratification (top).

From sequences to population dynamics

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- Bouckaert, Remco et al. (2012). “Mapping the origins and expansion of the Indo-European language family”. In: *Science* 337.6097, pp. 957–960. DOI: 10.1126/science.1219669.
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