Simulating Demographically Viable Populations

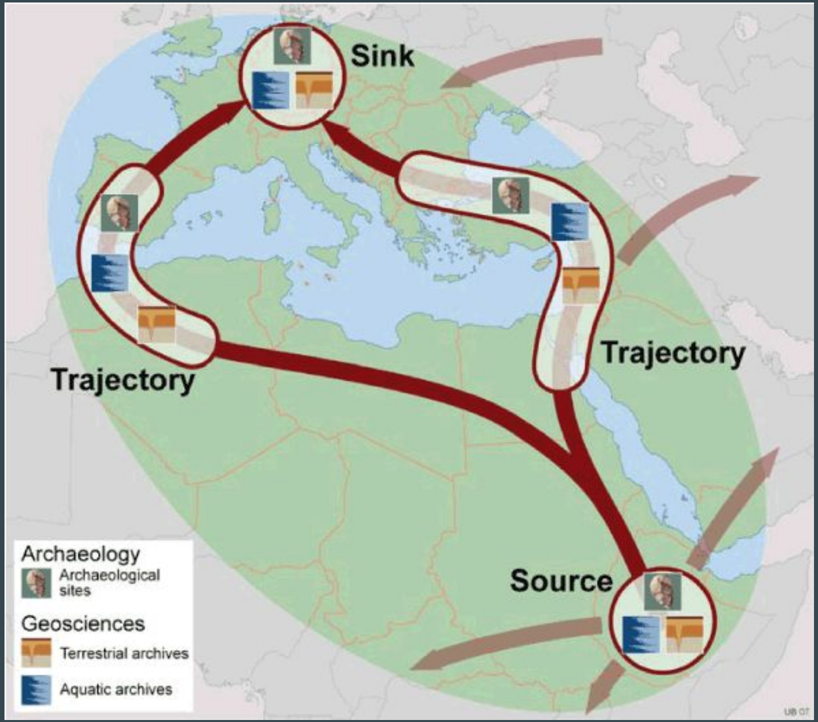
Stephan Henn, PhD candidate
SFB 806 "Our Way To Europe"

Universität
zu Köln

Outline

- Background of my Research
- Demography and Mobility
  - Colonization
  - Kinship Networks as resources
- Demographic Viable Populations
  - simple NetLogo Models
  - A more complex model: AMBUSH
- Demographic Viable Hunter-Gatherer Populations: 3 Representations
  - Moore: colonization
  - White: minimal viable group size
  - Wobst: minimum equilibrium size

SFB 806: Our Way To Europe

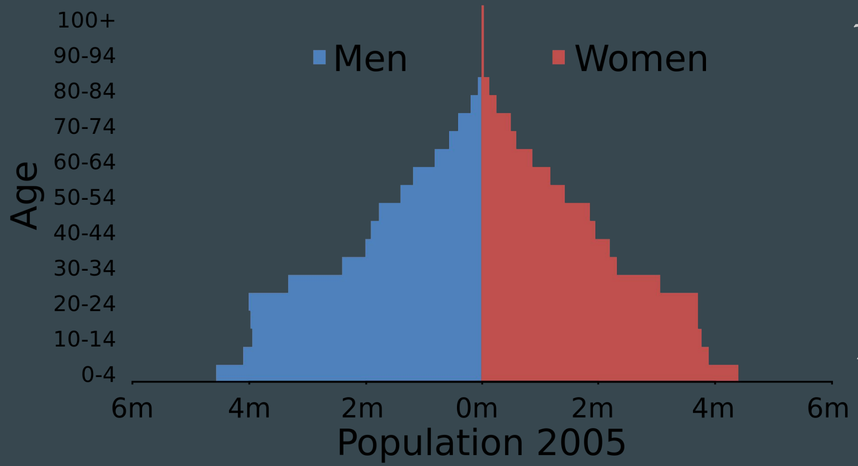


- Focus: The cultural-environmental context of the spread of anatomically modern humans (AMH) from their cradle in Africa to one of their “sinks” (Central Europe)
- Timeframe: In East-Africa it started about 190 kya with the first appearance of AMH in Ethiopia. AMH reached Europe around 40 kya from Central Asia and the Middle East.
- Several waves of migration
- Hunter-gatherer at least until Neolithic (12 kya)

Hunter-Gatherer

- Homo Sapiens lived exclusively as hunter-gatherers for the most of their history, from the beginning of speciation back around 350.000 years BC to at least the beginning in the Neolithic at around 12.000 BC.
- Hunter-gatherer may be characterized by their mode of subsistence, their sharing ethos, their egalitarianism, their immediate consumption of resources, their relation to the environment as a giving parent, their small group size and high mobility. Much of the social interactions are based on kin-relations.
- Whereas hunter-gatherer groups can vary substantially in their ways of living between each other as well as between different seasons, usually they live in small groups with a mean of 26 people.
- modern hunter-gatherer as analogues to past hunter-gatherers (frames of reference / ethnoarchaeology)

Demography



Egypt in 2005 (source: Wikipedia)

- Study of the size, structure, and distribution of populations, and spatial or temporal changes in them in response to birth, migration, aging, and death.
- Social, economic and cultural factors work by proximate causes:
  - contraceptive use
  - induced abortion
  - proportion women married
  - post-partum infecundability
- Stable population models
  - characteristic shape of age pyramid given by fixed birth and death rates

Interrelatedness of Demography and Mobility

- Demographic balancing equation:
  `end population = starting population + births - deaths + immigrants − emigrants`
- Demographic pressure often cited as a driver of mobility
  - also of parts of a population, like young people in growing populations
- Mating as motivation for mobility
  - mating rules, post marital residence rules
- Kinship relations motivate and enable mobility
- Mobility in a wider sense
  - spread of infectious diseases and of information is often density dependent
- Cumulative culture enabling humans to adapt needs large populations
  - else means of adaptation may be lost
- Colonisation needs viable populations

Example 1: Five Models of Human Colonization (Moore 2001)

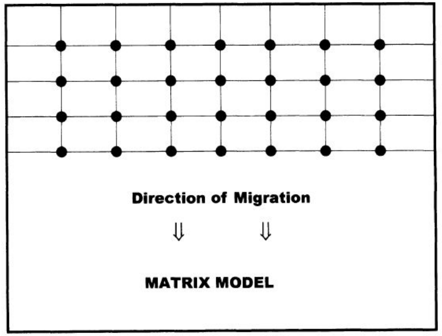


Figure 1. Matrix model of human colonization.

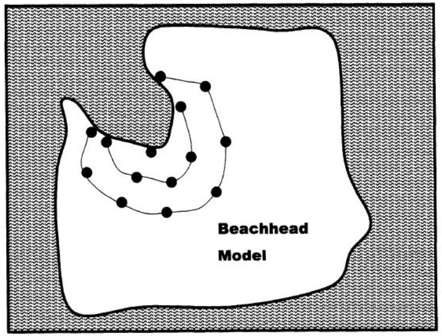


Figure 2. Beachhead model of human colonization.

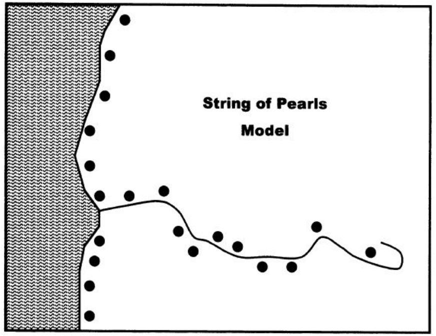


Figure 3. String of pearls model of human colonization.

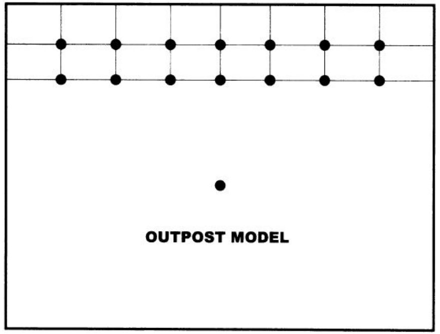


Figure 4. Outpost model of human colonization.

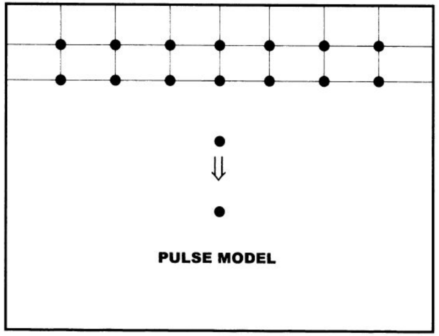
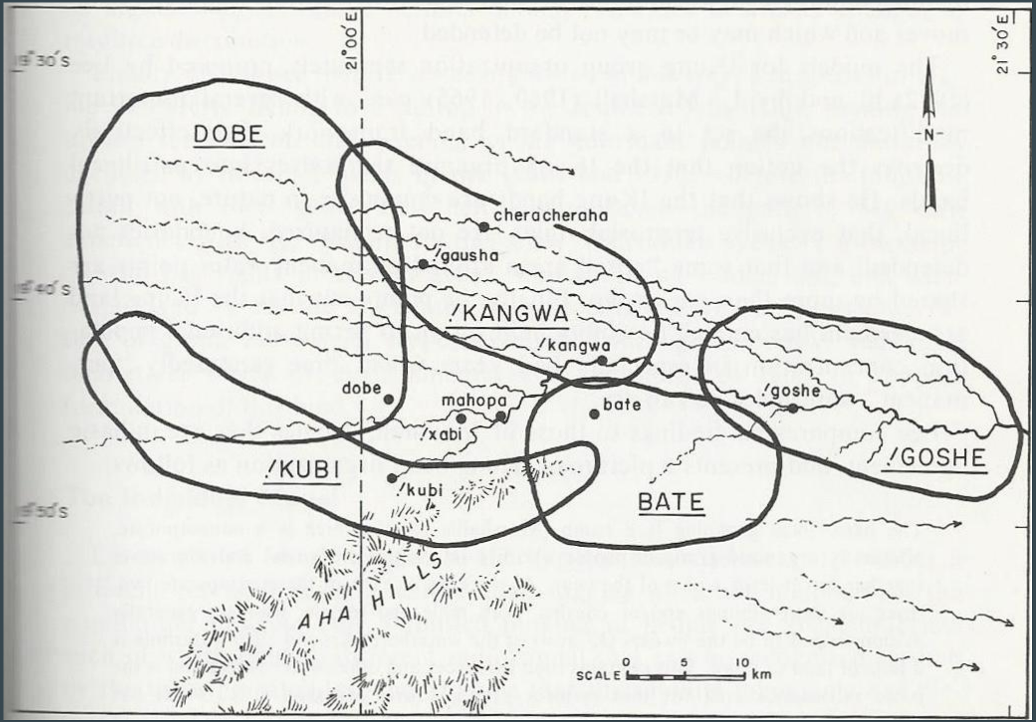


Figure 5. Pulse model of human colonization.

Example 2: The !Kung

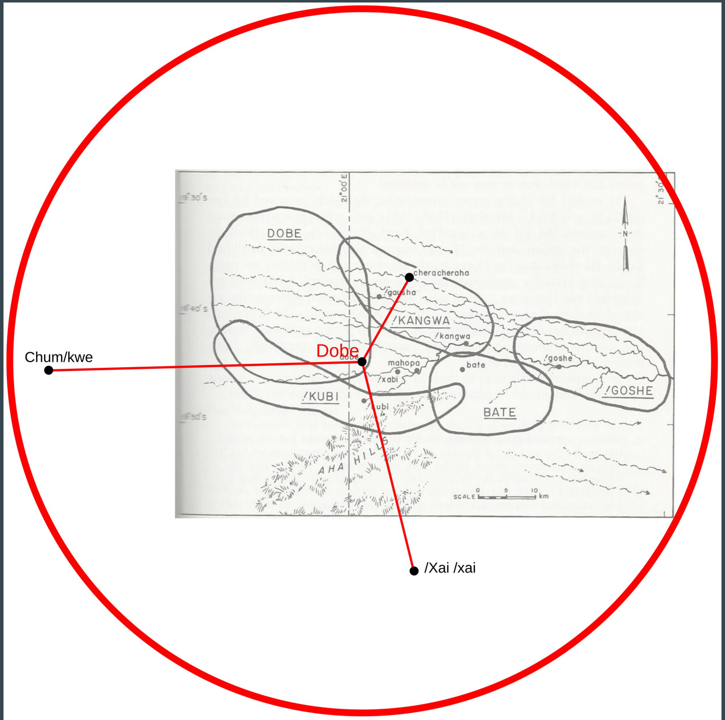
Landscape west of Dobe border with #Toma//gwe in the foreground. (Richard Lee 1964)

Example 2: Individual and Band Mobility - The Band Model



Lee's map of band territories with waterholes (permanent and semi-permanent)

Individual and Band Mobility - The Individual Model



- Distances between Dobe and other waterholes used by Dobe camp members. The red circle marks the average distance of 66.5 km between the birthplaces of spouses, parent and offspring.
- Yellen gives the range exploited by a nuclear family as about 2590 km^2.
- The social networks are based on kinship

Demographically Viable Populations

- viable (economic, genetic, demographic): survive over a certain time
- demographic balancing equation:
  `end population = starting population + births - deaths + immigrants – emigrants`
- simplify: assume a closed population
  `end population = starting population + births - deaths`
- So: a demographically viable population is one where over the longer run deaths <= births

Models of Population Dynamics

- How complex does the model need to be?
  - no “one size fits all” solution
- Model 1: birth and death rates
  - i.e. bacteria
- Model 2: Adding sex
- Model 3: Human populations

Model 1: Birth and Death Rates

a) How to simulate a viable population?
   i) simple version
      1) set probabilities for birth and death equal: problem: stochastic variations lead to extinction sooner or later: deaths = births holds only for infinitely large populations
      2) set probability slightly larger: some populations will die, some will experience an exponential growth
      3) set the size to 150: all populations will grow exponentially
b) If you want to keep the population size
   i) Make mortality (or fertility) dependent, i.e.
      1) on actual size (feedback)
      2) available resources (carrying capacity) (feedback)
   ii) Make the model resources explicit

Model 2: Adding Sex and Food

by Marco Janssen:
https://github.com/comses/intro-to-abm/blob/master/assets/netlogo/populationdynamics.nlogo

- explicit modeling of resources
- mating
- unstable or stable systems with cycles (see first Lotka–Volterra equation)

See also the Wolf Sheep Predation model in the NetLogo models library.

Model 3: Human Population Dynamics

- Fertility and Mortality depend on age and sex
- two-sex problem: individuals need to find a suitable mating partner
    - cultural rules affecting marriage
        - age of eligibility
        - kinship rules
- Birth Spacing
    - cultural rules (postpartum tabo)
    - postpartum amenorrhea

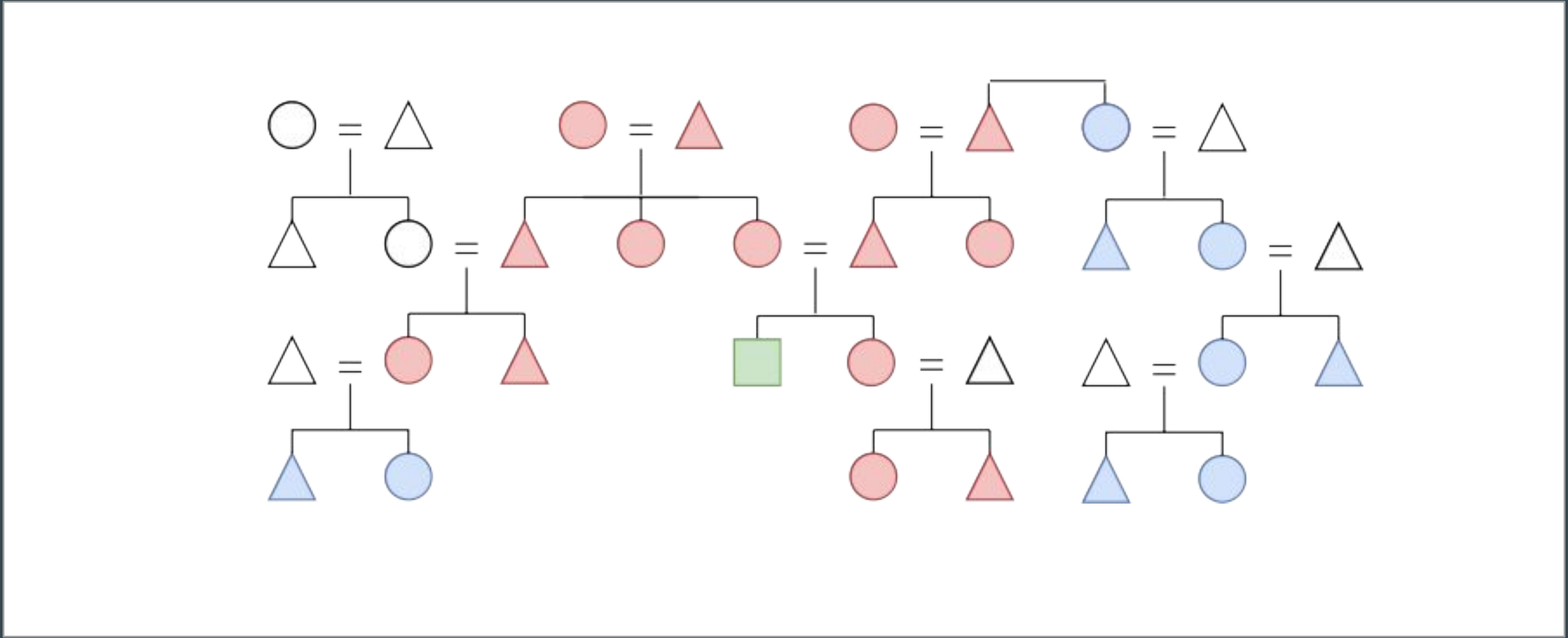
Model 3: The Dobe !Kung

- A more complex model has been developed by Howell and Lehotay (1978) for the Dobe !Kung:
  - using a standard life tables derived from comparison of world populations
  - using a fertility schedule derived from her fieldwork data
  - using culture specific mating rules
- The model was intended to complement her fieldwork data: to test if her conclusion are valid and to fill some gaps
  - Thus it includes lots of demographic metrics, i.e. social structural ones like average number of living siblings per age group

AMBUSH: Overview

- agents = individuals; starts with an already defined set of individuals;
- discrete time: 1 step = 1 year (max 500, incl. 100-150 initialization phase)
- kin ties are created at the birth of an agent and by marriage and kept as lists
- important mechanisms concern birth and death events and marriages
- probabilities are related to individuals (death, age of eligibility, birth) and to groups (only divorce)
- At each time step happen
  - birth events
  - death events
  - divorce events
  - marriage events
- Individuals can remarry immediately

Marriage Rules



Input Probabilities

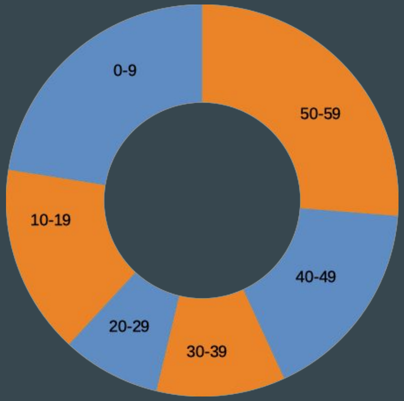
	Males		Females		
Age	Death (d_x)	Eligibility for marriage	Death	Eligibility for marriage	Fertility
0	29546		25573		
1	3119		3305		
2	3119		3305		
3	3119		3305		
4	3119		3305		
5	543		614		
6	543		614		
7	543		614		
8	543		614		
9	543		614		
10	373		455		
11	373		455		
12	373		455		
13	373		455		
14	373		455	33	
15	491		571	33	1
16	491		571	33	15
17	491		571		30
18	491		571		43
19	491		571		47
20	663		677		47
21	663		677		49
22	663	15	677		51
23	663	15	677		48
24	663	15	677		47
25	693	15	710		46
26	693	15	710		43
27	693	15	710		40
28	693	5	710		38
29	693	5	710		36
30	741		743		34
31	741		743		32
32	741		743		31
33	741		743		29
34	741		743		27
35	793		748		26
36	793		748		25
37	793		748		24
38	793		748		23
39	793		748		21

Females		
Death	Eligibility for marriage	Fertility
25573		
3305		
3305		
3305		
3305		
614		
614		
614		
614		
614		
455		
455		
455		
455		
455	33	
571	33	1
571	33	15
571		30

- Up to age 80
- Other probabilities include the total fertility rate (TFR = 5.8, up from 4.69) and the probability of divorce (p = 0.2).
- High infant mortality (33% within the first year for males)

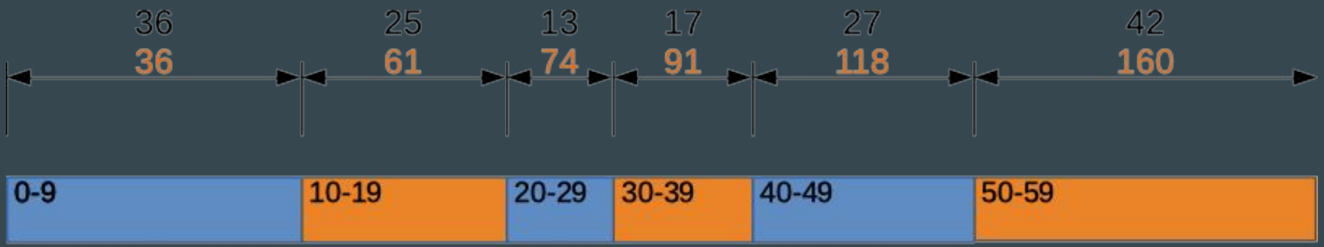
Taken from Howell 1979:282f, Table 14.1

Roulette Wheel Sampling




```
let p a  uniform random number < sum of all element's values
for each element in list:
    if p - element's value <= 0: return element
    else set p = p - element's value
```

In NetLogo you can use `rnd:weighted-one-of-list` from the Rnd extension.



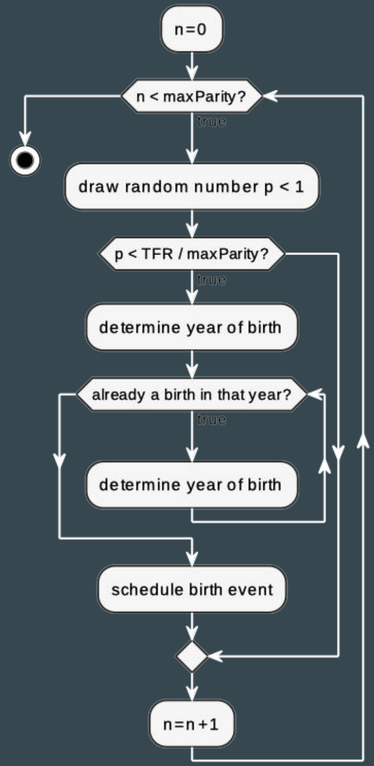
Human Fertility

Natural Fertility Populations (no use of contraception or induced abortion):

Group	Total Fertility Rate
Hutterites	12.4
Ache (Paraguay)	8
Agta (Luzon, Philippines)	7
Dobe !Kung (Botswana)	4.7
Batek (Malaysia)	3.8

For comparison EU in 2015: 1.58 TFR.

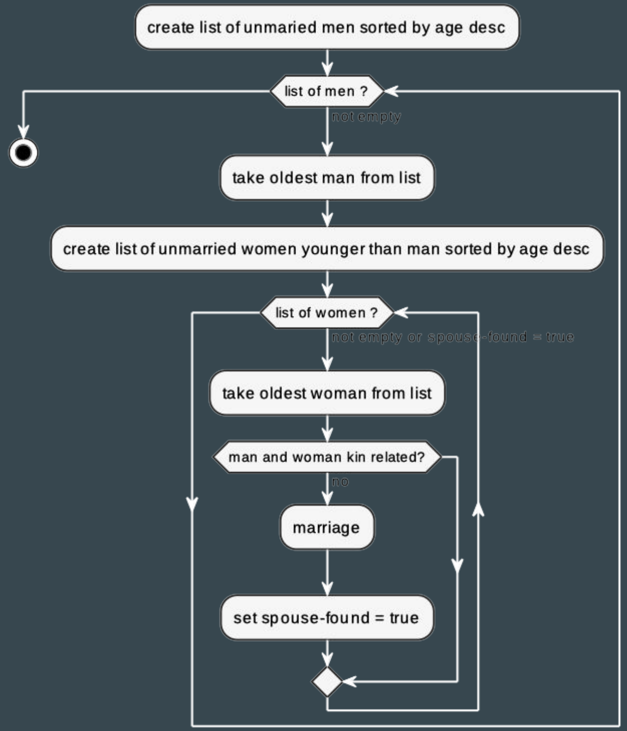
The Simulation of Birth and Death



Simulation of birth events

- Birth and death events are schedule beforehand at the time of marriage
- Empirical data on fertility used as first estimates of underlying probabilities, and then fitted
- Total Fertility Ratio as expected value of a number of binomial trials (max. 9)
- Exact year of birth determined by age specific fertility schedule (roulette wheel sampling)
- Birth events that fall outside of the time of that marriage are discarded
- Year of death based on established life tables

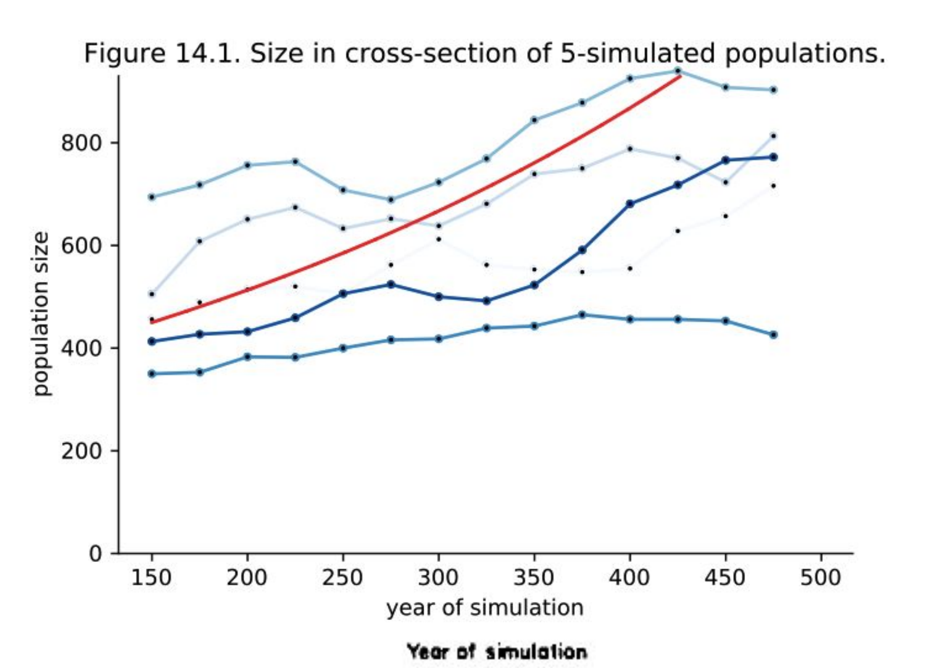
Marriage



- Runs every time step / year
- From a certain age on individuals become eligible for marriage and enter the “marriage pool”
- Men must be older than women
- Marriage prohibitions exclude persons related by consanguinity, but only up to first cousins.
- Frequent divorces and remarriages
- No polygamy
- Individuals with not marriage for 5 years are excluded from the “marriage pool”

Simulation of marriages

AMBUSH: Some Results



- high fluctuations in small populations although the mean net growth rate per year is positive (.0016) ("two-sex problem" of marriage)
- careful with attribution of causes
- Different "capacities" of women and men during their life cycle (→ structural "gerontocracy")

Replication of AMBUSH

Why replicate?

- Replicability is a hallmark of science: Only if results can be replicated they can be considered as valid
- As reference model or even core of a social-network oriented model of !Kung mobility
- Helps my understanding of / “get a feeling for” hunter-gatherer demography
- Learn how others representations of phenomena
- Making the model available to the interested public again

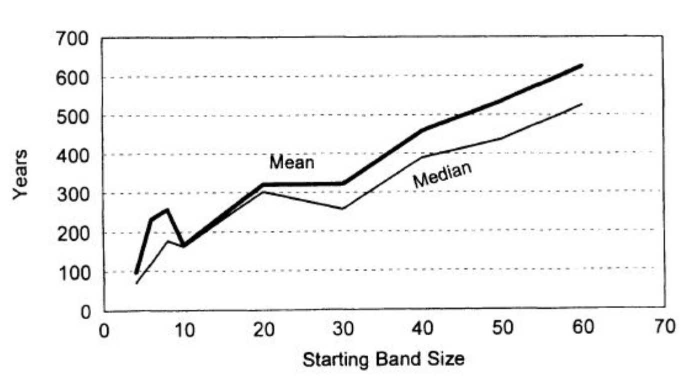
Some Results: Demographically-Viable Hunter-Gatherer Populations

- The two-sex problem makes human population dynamics more volatile and more sensitive to size: in a large enough population stochastic variations may level out, but not in small scale populations.
- Already taken into account: **maximum** size of a group as bounded by resources
- But what is the **minimum** size needed to get populations out of the critical numbers?
- The hunter-gatherer dilemma: “groups large enough to be demographically viable are too large to be economically viable, while groups small enough to be economically viable on a day-to-day basis are not demographically viable over the long term” (White 2017)

3 Different Purposes, 3 Different Representations

- Wobst, H. M. (1974). Boundary Conditions for Paleolithic Social Systems: A Simulation Approach.
- Moore, J. H. (2001). Evaluating Five Models of Human Colonization.
- White, Andrew (2017) A Model-Based Analysis of the Minimum Size of Demographically-Viable Hunter-Gatherer Populations.

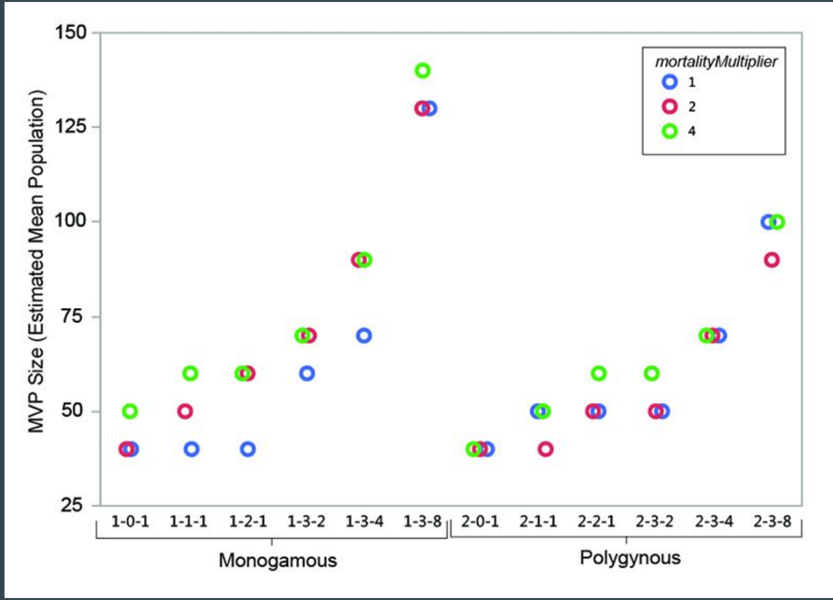
Moore 2001: Compare Colonization Models



Years to extinction (Moore 2001)

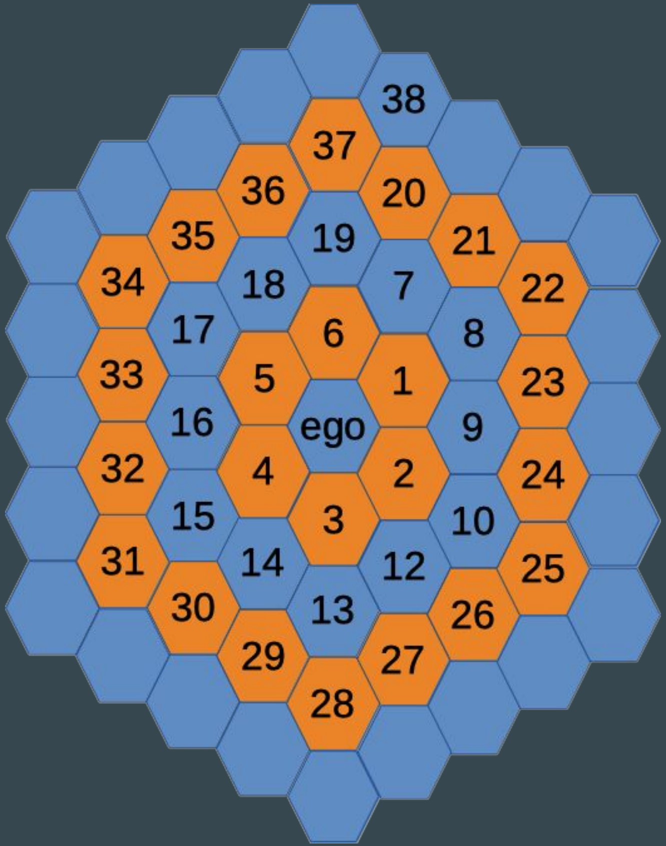
- Purpose: Compare the success rate of different colonization models from a demographic perspective
  - Problem of “initial size”
- Method: 1 use populations with high mortality and low fertility and measure time it takes for groups of different sizes until extinction
  - Result: high initial fluctuations until ”Malthusian Takeoff” (exponential growth)
- Method 2 - Connectedness: Connect a band of size 100 and compare it’s survival if connected to 1 or more other bands of the same size.
  - Result: great Difference between not connected or connected, but less between connected to one or more than one

White 2017: Minimum Viable Group Size



- Purpose: Explore How small viable hunter-gatherer populations can get
- MVP is calculated by determining the population size below which fewer than 95% of the runs survived a 400-year period
- White varied TFR, marriage rules and size using data from known hunter-gatherers; time step: 1 week;
- Mortality controlled by feedback based on population size
- Results:
  - viable already at size 50 given incest is allowed
  - viable from 150 on even in groups with strong marriage restrictions

Wobst 1974: Minimal Equilibrium Size



- Purpose: Hunter-gatherer want to minimize the costs of maintaining a network. How small can that network be while everyone finds a suitable mate?
- MES defined as “the mean or median number of persons living inside the radius within which marriages are contracted” (Wobst 1974:161ff)
- Setup:
  - 61 cells, each exploited by a “minimal band” of about 25 members (bounded by feedback)
  - Males select closest suitable spouse
  - spatial: residential rules and fission and fusion
- Results:
  - MES mean 79-332, median 75-200 people (1 or 2 tiers = 175 and 475)

Some “Practical Tips”

- Keep a lab book
- If you have the chance to: organize local coder groups for co-coding, code walktroughs etc.
- Think beforehand what metrics you will need and how and where to compute them
    - Calculating in NetLogo takes time from the simulation runs, but can be easier and helps debugging
- Jupyter notebook (for R or python)
    - Combine dokumentation and code
    - Shareable (i.e. Binder](https://mybinder.org/ or Microsoft Azure Notebooks https://notebooks.azure.com/#)
- Replicate existing Models
    - Helps you understand the model better
    - Improves verification and validation of the model

Thank You!

Credits

All Photos from Richard Lee can be found at the University of Toronto's T-Space Repository https://tspace.library.utoronto.ca/
The map from Namibia is from the German Wikipedia page about Namibia https://de.wikipedia.org/wiki/Namibia

References

Howell, Nancy, and Victor A. Lehotay (1978) Ambush: A Computer Program for Stochastic Microsimulation of Small Human Populations. American Anthropologist 80(4): 905–922.

Howell, Nancy (1979) Demography of the Dobe !Kung. Population and Social Structure. New York: Academic Press.

Moore, J. H. (2001). Evaluating Five Models of Human Colonization. American Anthropologist, 103(2), 395–408.

Wilensky, Uri and Rand, William (2007). 'Making Models Match: Replicating an Agent-Based Model'. Journal of Artificial Societies and Social Simulation 10(4)2

Wobst, H. M. (1974). Boundary Conditions for Paleolithic Social Systems: A Simulation Approach. American Antiquity, 39(2), 147–178.

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – Projektnummer 57444011 – SFB 806