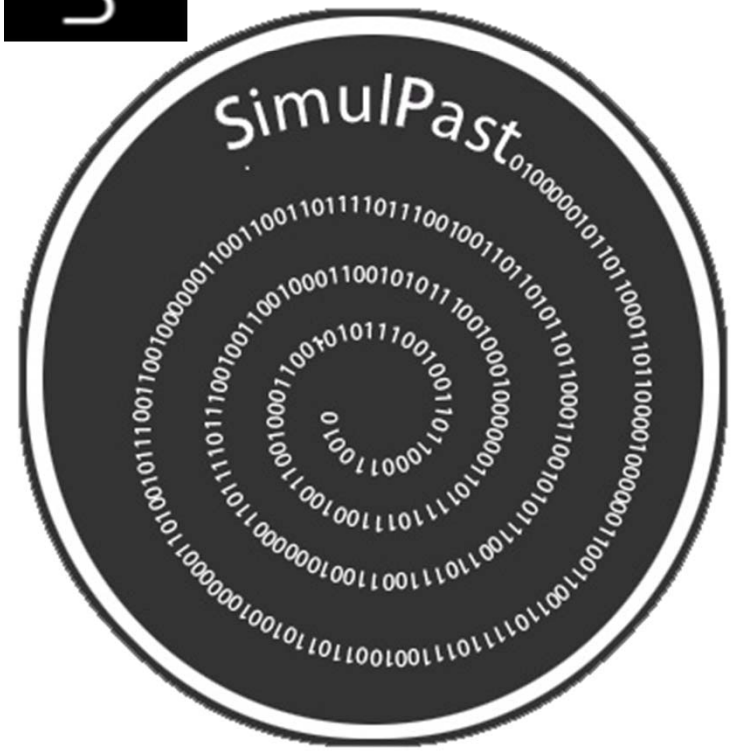
Synthesis between demic and cultural diffusion in the Neolithic transition in Europe



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Complex Systems in Prehistoric Research
European Conference on Complex Systems
Barcelona, September 19th 2013

The Neolithic transition in Europe

The Neolithic spread gradually from the Near East across Europe.

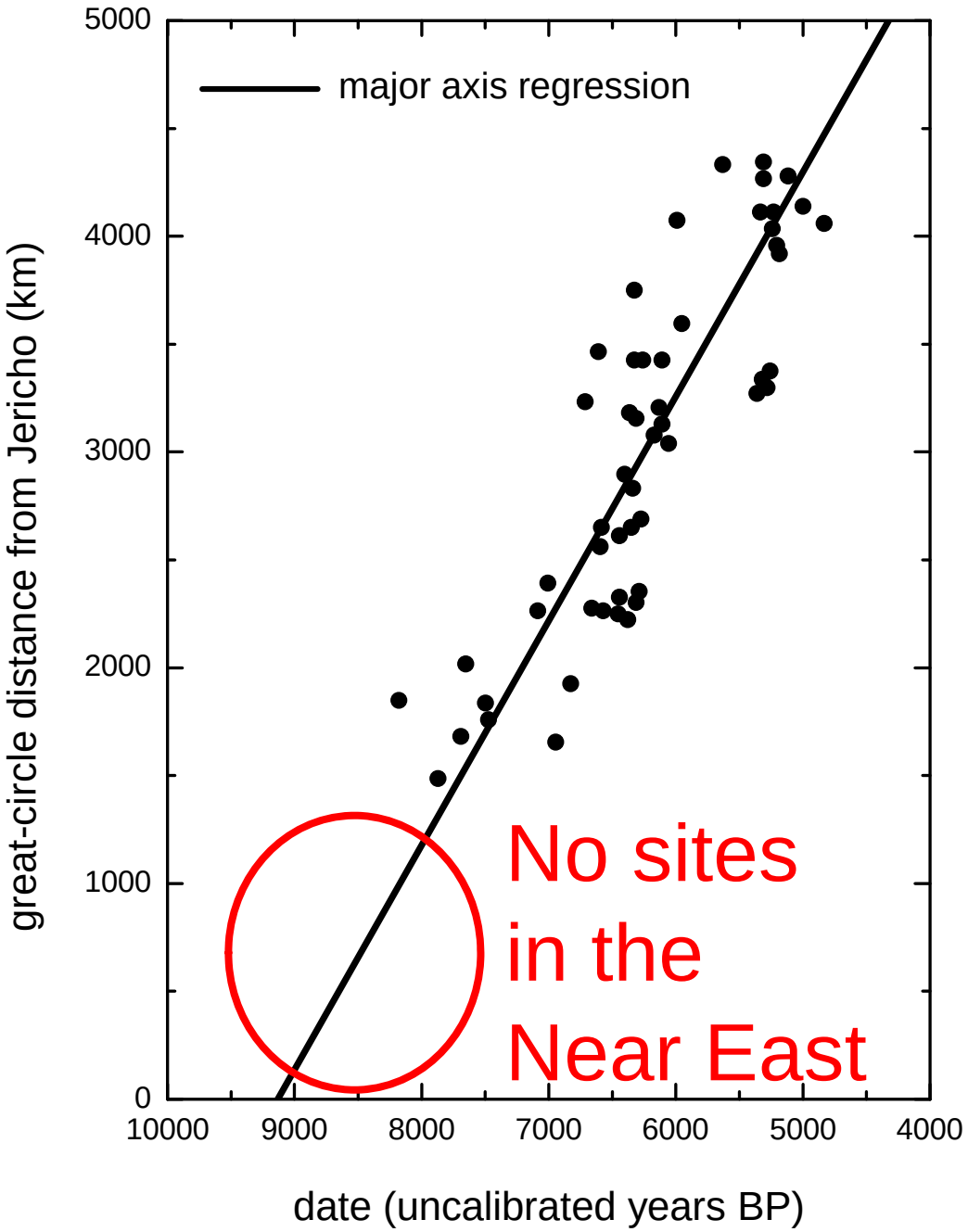
Demic model: it assumes that it was mainly driven by the spread of farming populations.

Cultural model: it assumes that it was mainly a spread of ideas (transmission of domestic plants, animals and knowledge from farmers to hunter-gatherers).

Can demic and/or cultural models describe the archaeological data?

Plan of this talk

1. Data (4 slides)
2. Demic models (5 slides)
3. Cultural models (4 slides)
4. Demic-cultural models (6 slides)



Ammerman & Cavalli-Sforza (1971)

53 sites in Europe

speed = 1.0 km/yr

(0.8-1.2 km/yr)

r = 0.89 (Jericho, highest-*r* origin)

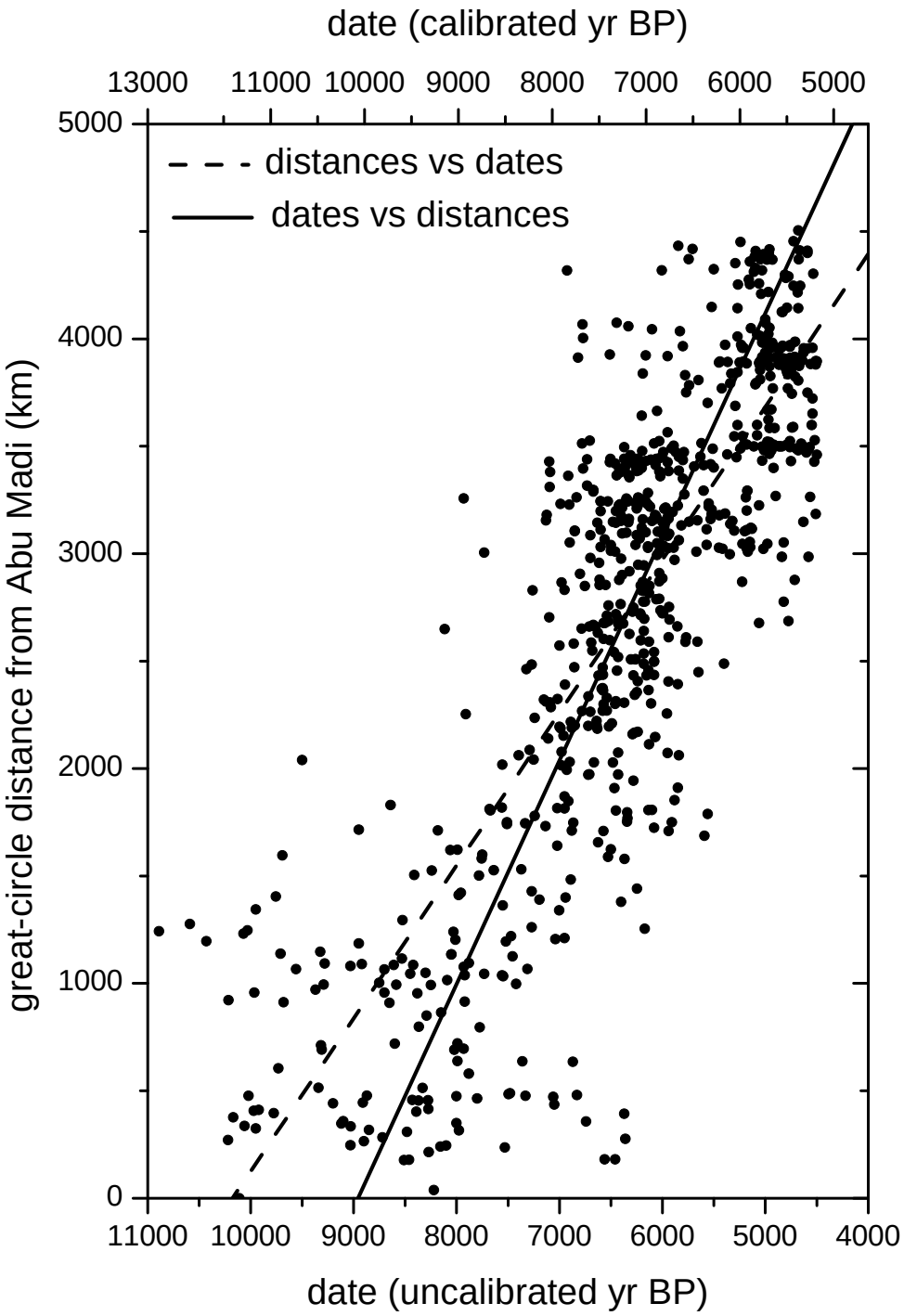
Gkiasta, Russell, Shennan & Steele, *Antiquity* (2003)

510 sites in Europe

speed = 1.3 km/yr (major axis regression)

r = 0.73 (Jericho, maybe not highest-r origin)

No error range, but similar to the range
0.8-1.2 km/yr by Ammerman & Cavalli-Sforza (1971)



Pinhasi, Fort & Ammerman, *PLoS Biol.* (2005)

735 sites in Europe & the Near East

speed = 0.6-1.3 km/yr

r = 0.83 (highest-r origins for great circles & shortest paths)

Fort, Pujol & vander Linden, *Amer. Antiq.* (2012)

903 sites in Europe (vander Linden)

+ 16 Near-Eastern sites (PPNB/C)

speed = 0.5-1.3 km/yr

$r = 0.7$ (Hemar, oldest PPNB/C site)

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Ammerman & Cavalli-Sforza (1973)

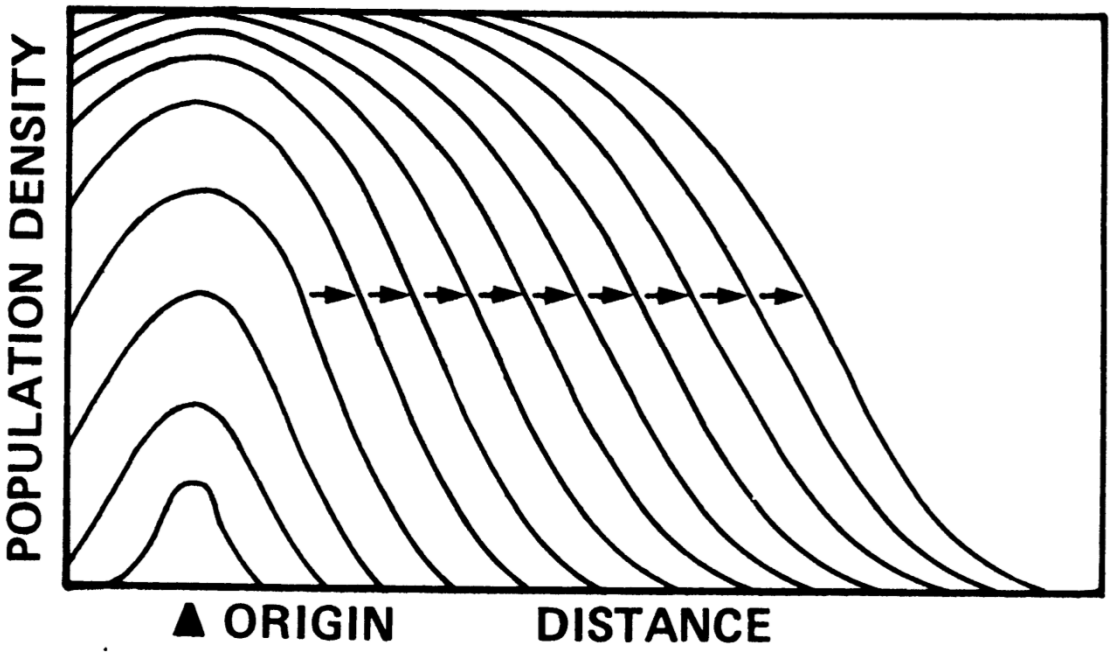


FIGURE 5.2. Fisher's model of a population wave of advance. This graphic representation shows the rise in local population density expected with increasing distance

demic model

speed:

$$v_{Fisher} = \sqrt{\frac{r\ m}{T}}$$

Preindustrial farmers:

$$\left.\begin{array}{l} \text{Reproduction}: \quad r = 0.032\ \text{yr}^{-1} \\ \text{Mobility}: \quad m = 1544\ \text{km}^2 \\ \text{Generation time}: \quad T = 25\ \text{yr} \end{array}\right\} \rightarrow v_{Fisher} = 1.4\ \text{km/yr}$$

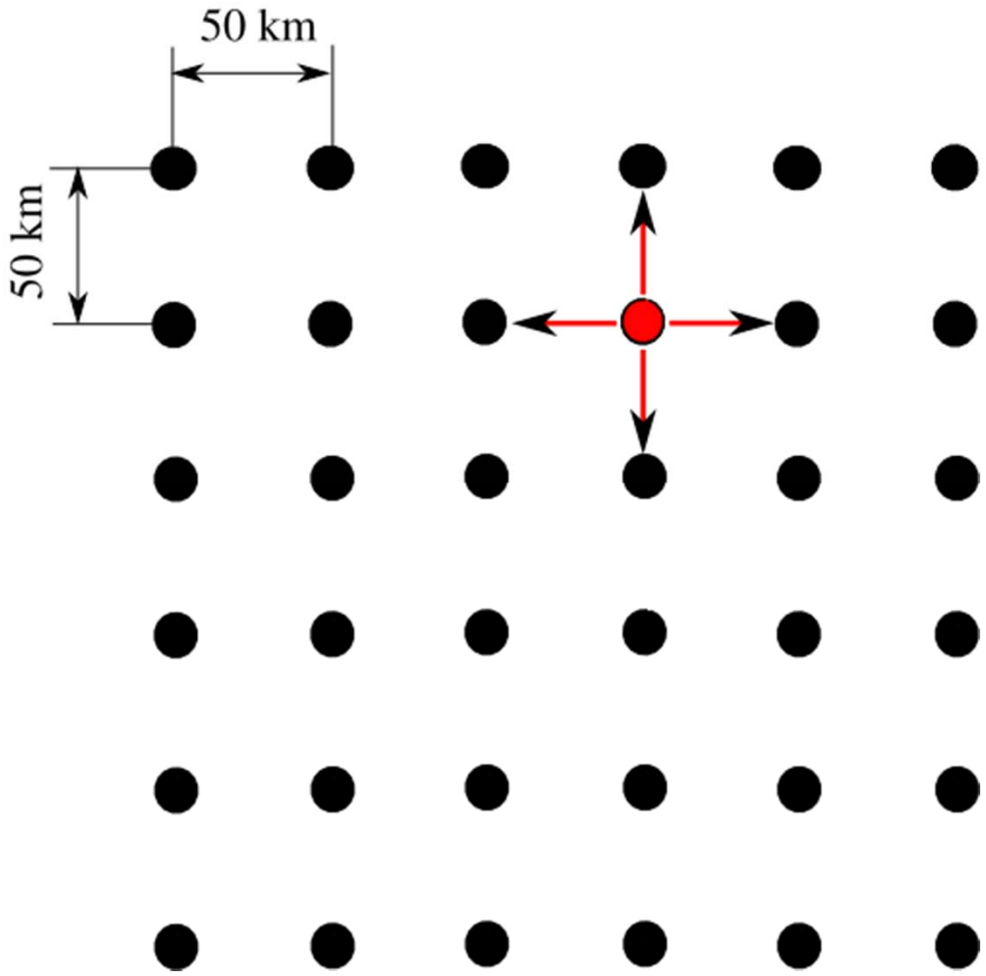
Time-delayed demic model

It takes into account that children spend some time with their parents before becoming adults and dispersing

speed: $$v = \frac{v_{Fisher}}{1 + \frac{r\,T}{2}} = 1.0\ \mathrm{km/yr} \rightarrow 40\%$$

Fort & Méndez, *Phys. Rev. Lett.* (1999)

Simplest homogeneous demic model



$0 < p_e < 1$ persistence

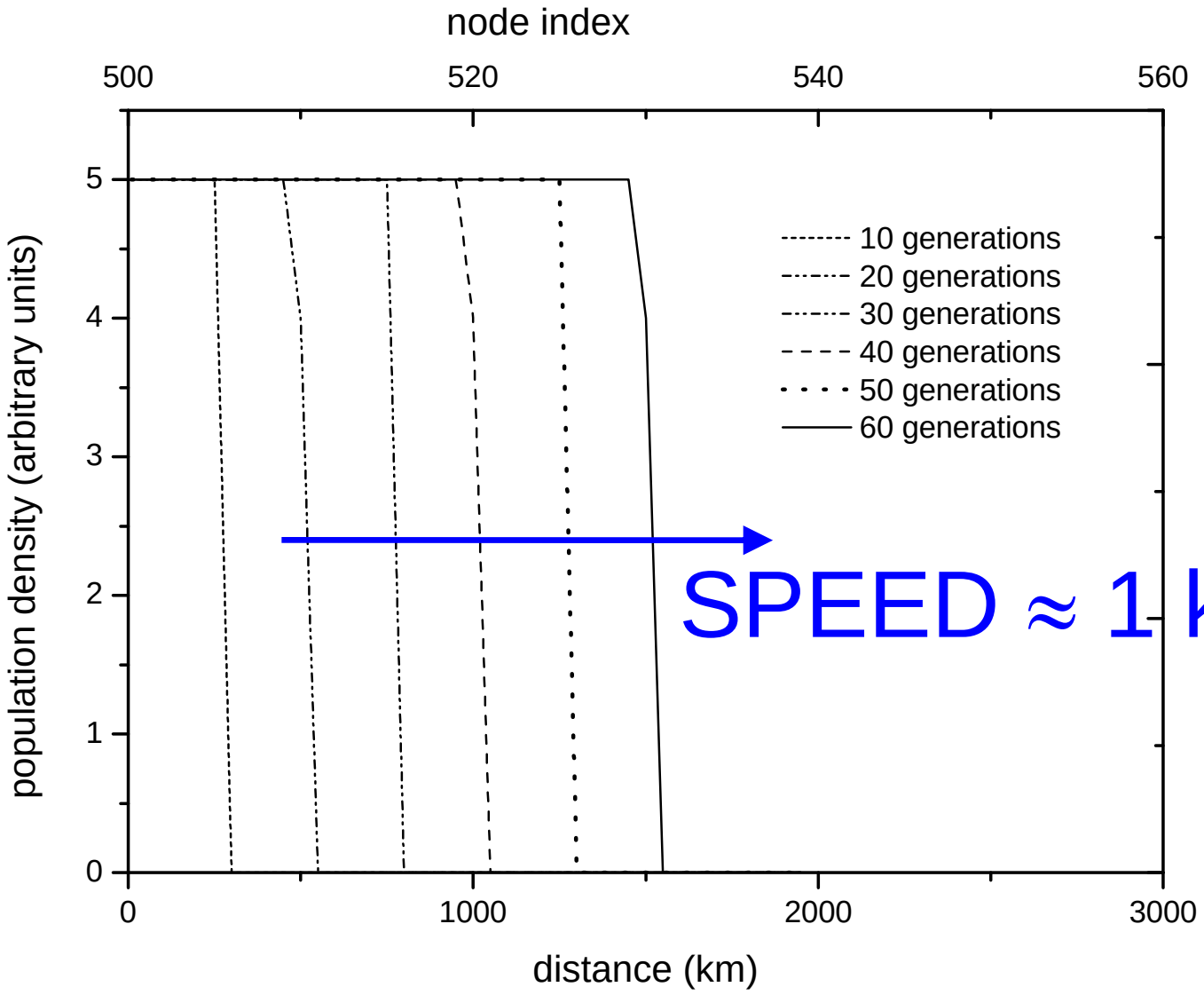
a fraction p_e stays

$(1-p_e)/4$ move in each direction

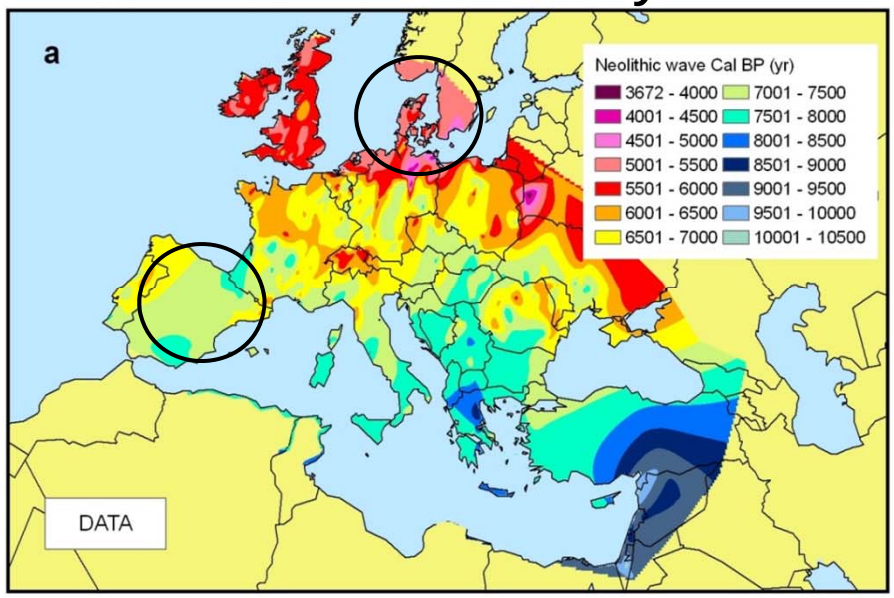
$P(t+1)=Ro\ P(t)$

Pre-industrial farmers:
Reproduction: Ro=2.2
per generation (25 yr)
p_e= 0.38, d= 50 km

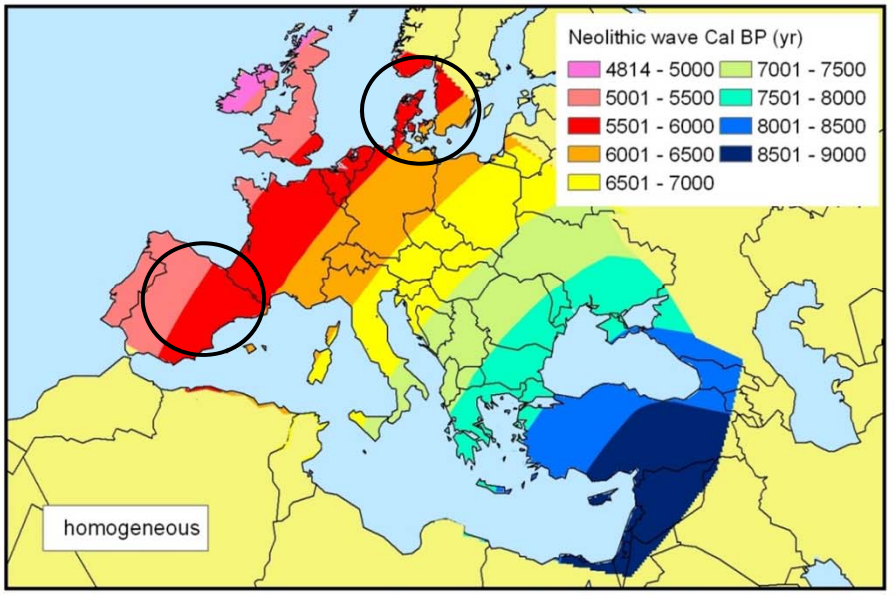
Simulated demic front of farmers



DATA → 1 km/yr



HOMOGENEOUS MODEL → 1 km/yr



The homogeneous model agrees with the average observed speed but not with local features (circles).

Non-homogeneous models (not explained in this talk) can improve the agreement:

Fort, Pujol & vander Linden, *Amer. Antiq.* (2012)

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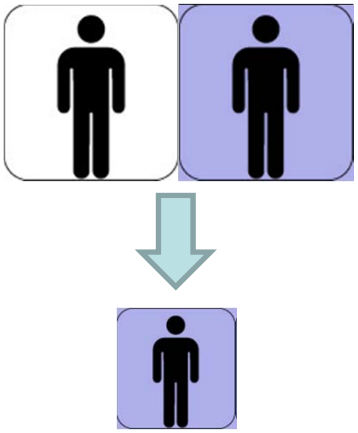
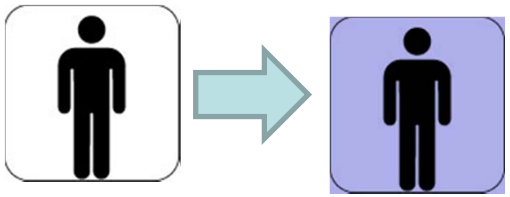
Cultural models

Cultural transmission takes 2 forms



1) Vertical transmission is due to interbreeding between farmers and hunter-gatherers



2) Horizontal/oblique transmission is due to acculturation

Vertical transmission

Cavalli-Sforza & Feldman (1979)

Population numbers after *(P')* and before *(P)* cultural transmission (during 1 generation):

$$\begin{cases} \text{farmers } (F): \quad P_F' = P_F + \eta \dfrac{P_F P_H}{P_F + P_H} \\ \text{hunter} - \text{gatherers } (H): \quad P_H' = P_H - \eta \dfrac{P_F P_H}{P_F + P_H} \end{cases}$$

η = interbreeding parameter ($P_H \ll P_F \rightarrow$max. η =1)

This effect on the speed seems **small** (e.g., <9% if η<0.2)

Fort, *Phys. Rev. E* (2011)

Let us consider horizontal/oblique transmission

Horizontal/oblique transmission

Cavalli-Sforza & Feldman (1979)
Boyd & Richerson (1985)
Fort (2012)

Population numbers after *(P')* and before *(P)* cultural transmission (during 1 generation):

$$\begin{cases} \text{farmers } (F): \quad P'_F = P_F + f\dfrac{P_F P_H}{P_F + \gamma P_H} \\ \text{hunter} - \text{gatherers } (H): \quad P'_H = P_H - f\dfrac{P_F P_H}{P_F + \gamma P_H} \end{cases}$$

f = intensity of cultural transmission

γ = preference of *H*s to copy *F*s rather than *H*s (if $\gamma < 1$)

Lotka-Volterra eqs. are not realistic as they are not derived from cultural transmission theory

Why not a purely cultural model?

1. Agriculture is a complex cultural trait→ probably copied only at short distances → the predicted speed would be << 1 km/yr.

2. We cannot ignore that humans move!

Thus we consider demic-cultural models

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Demic-cultural models

Fort, *PNAS* (2012)

2 ways to compute the front speed, same results:

1) Using equations

2) Using simulations on a grid

Steps:

1. reproduction (logistic)
2. cultural transmission (horizontal/oblique)
3. dispersal (distance kernel)

The order of events does not change the speed

$$\begin{cases} P_F' = P_F + f\,\dfrac{P_F P_H}{P_F + \gamma P_H} \approx P_F + C\,P_F \\ P_H' = P_H - f\,\dfrac{P_F P_H}{P_F + \gamma P_H} \approx P_H - C\,P_F \end{cases}$$

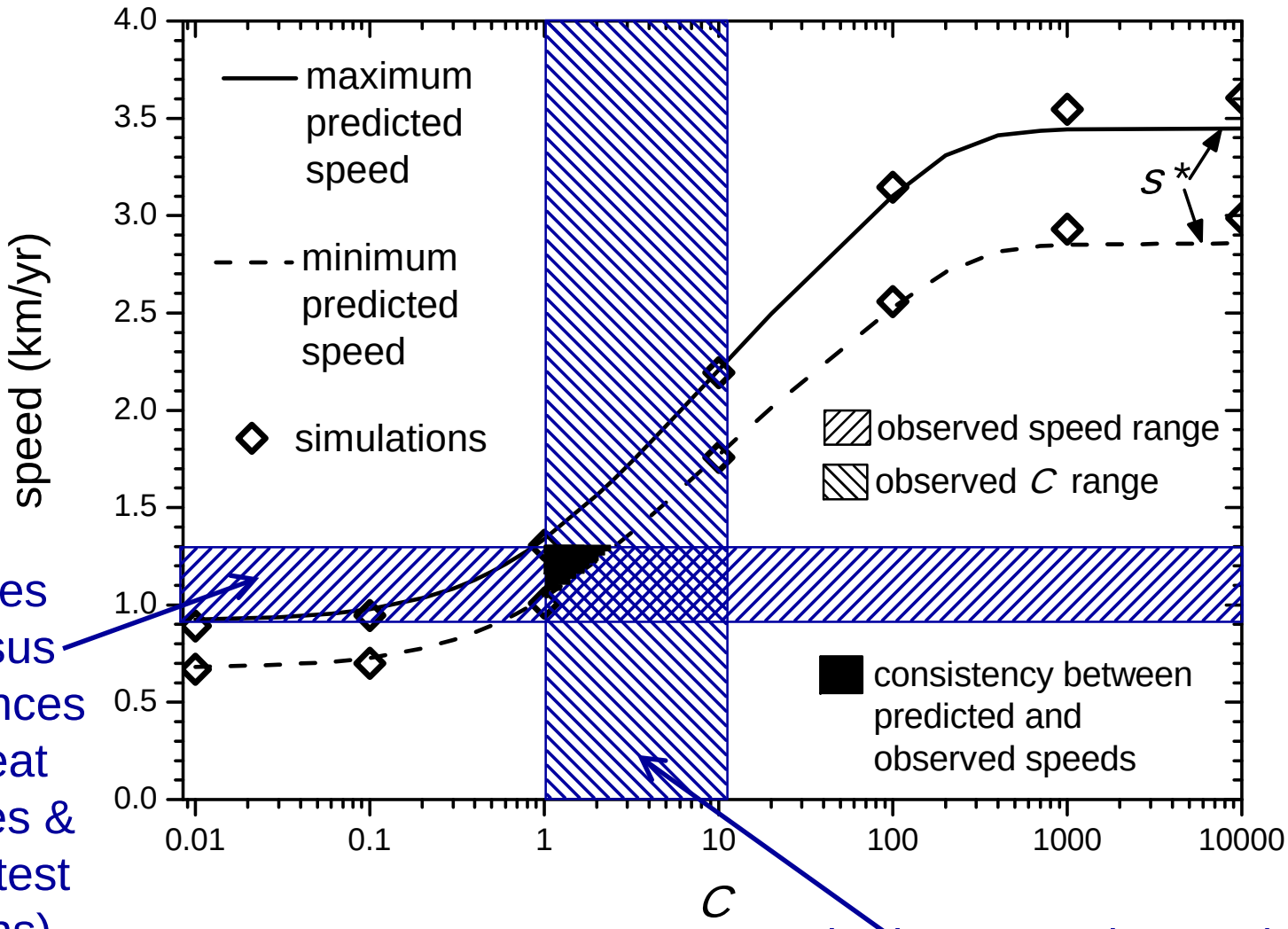
if $P_F \ll P_H$, then

$C = \frac{f}{\gamma}$ is the number of *H*s converted by farmer

The front speed does not depend on f and γ separately but only on $C = \frac{f}{\gamma}$

This case ($P_F \ll P_H$) shows that Lotka-Volterra eqs. are not realistic

Effect of horizontal/oblique diffusion on the front speed



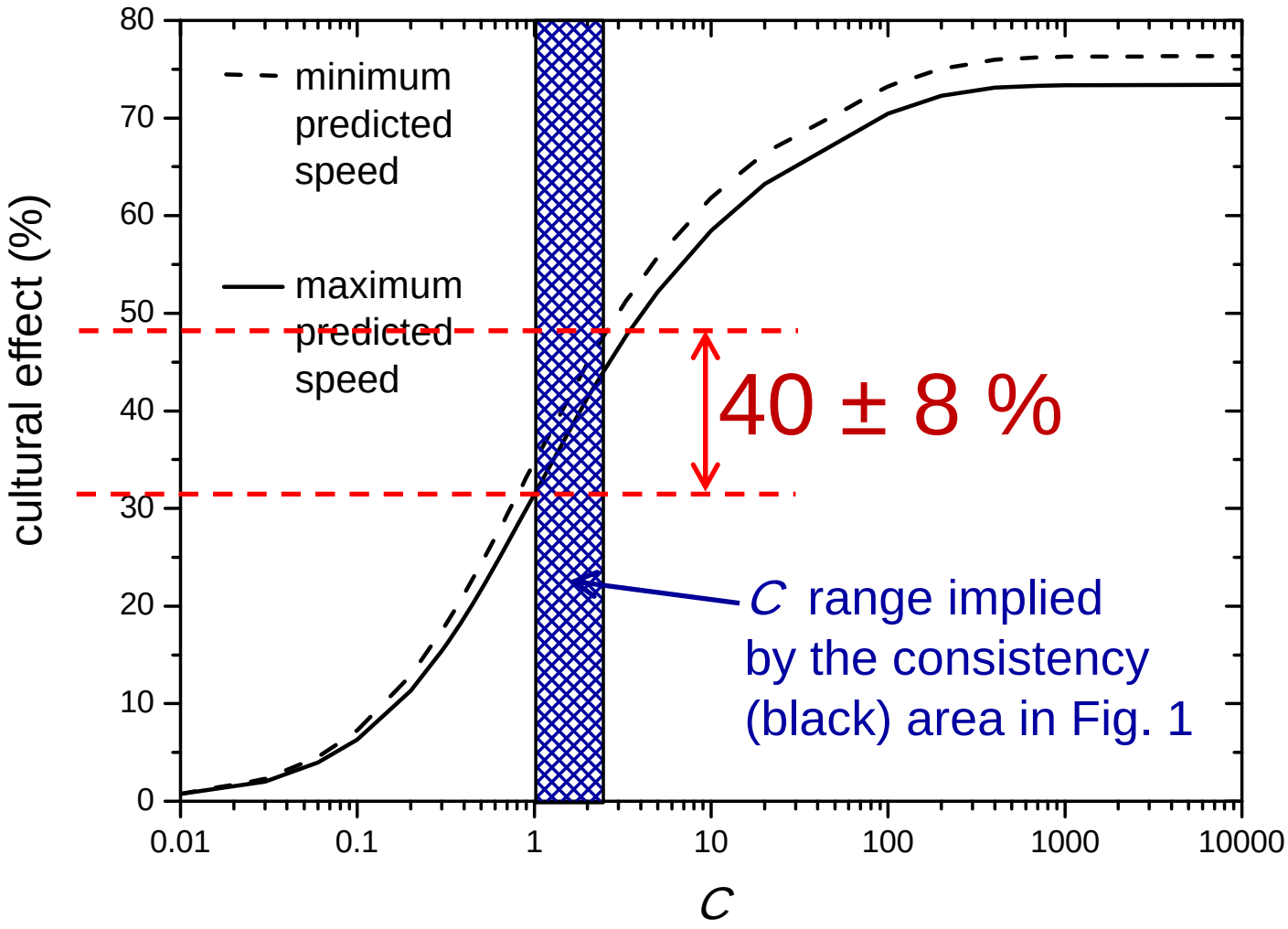
Dates versus distances (great circles & shortest paths)

Fort, *PNAS* (2012)

Ache hunter-gatherers (Paraguay)

Effect of cultural diffusion

Effect (%) = (speed – demic speed) /speed · 100



Fort, *PNAS* (2012)

Effect of cultural transmission on the Neolithic spread

Genetics: no clear conclusion
(depends strongly on the genes, populations demographic models…)

Archaeology:

40 % cultural

60% demic

Cultural diffusion cannot be neglected, but demic diffusion seems more important

Frequency-dependent (conformist) effect

This is a more refined model, see e.g.:

- Boyd & Richerson (1985)
- Kandler & Steele (2009)
- Henrich (2001) → it explains the slow initial growth of innovation S-shaped curves

$$\begin{cases} P_F' = P_F + \dfrac{P_F P_H}{P_F + \gamma P_H}\left(f + h\left[2\dfrac{P_F}{P_F + P_H} - 1\right]\right) \\ P_H' = P_H - \dfrac{P_F P_H}{P_F + \gamma P_H}\left(f + h\left[2\dfrac{P_F}{P_F + P_H} - 1\right]\right) \end{cases}$$

$h = 0 \rightarrow$ previous model

- If $u = P_F/(P_F + P_H) > 1/2 \rightarrow$ positively-biased;
- If $u < 1/2 \rightarrow$ negatively-biased $\rightarrow$slow initial growth.

Exactly the same results as for the previous model

Questions?