Large-scale meta-population patch models of infectious diseases on Cray machines

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10 May 2007

Health Protection Agency

A non-departmental public body

Health Protection Agency

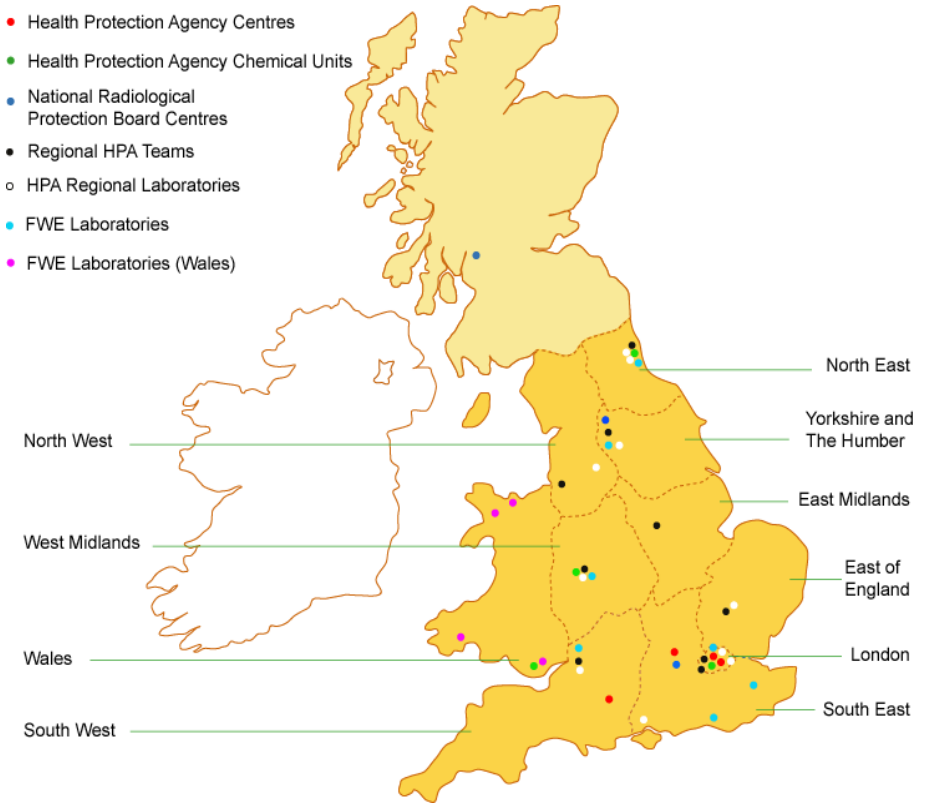
- Centre for Infections
- Centre for Emergency Preparedness and Response
- Centre for Radiation, Chemical and Environmental Hazards
- Local and Regional Services

Microbial Risk Assessment -
(Part of the Emergency Response Division)

Emerging and re-emerging disease threats:
Contingency planning
Predictive modelling
Training exercises
Emergency response.

Bioterrrorism, Pandemic Influenza, Legionella, Zoonotic Diseases.

Fostering international collaborations: *EU* (Two projects INFTRANS, MODELREL), *G8* (Conferences and publications), WHO, European CDC, links to US modelling groups via MIDAS



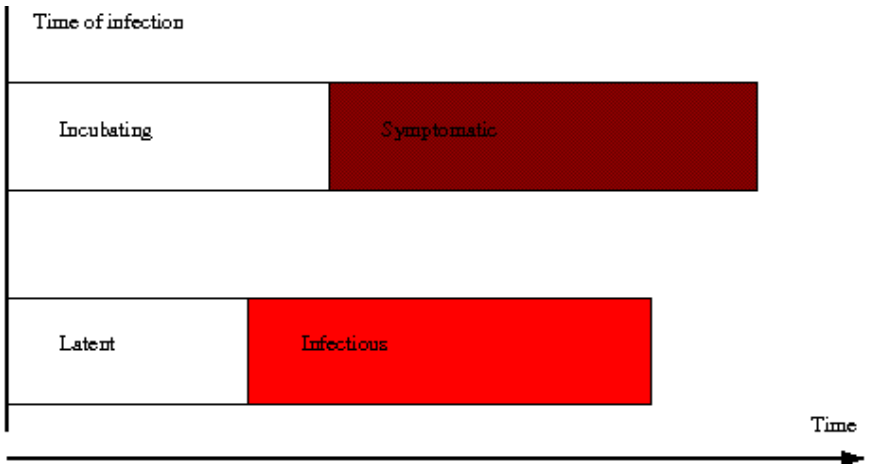
Overview

- Infectious disease threats
- Metapopulation models
  - Parameterisation for the UK
  - Parallel implementation
- Performance analysis
- Further work

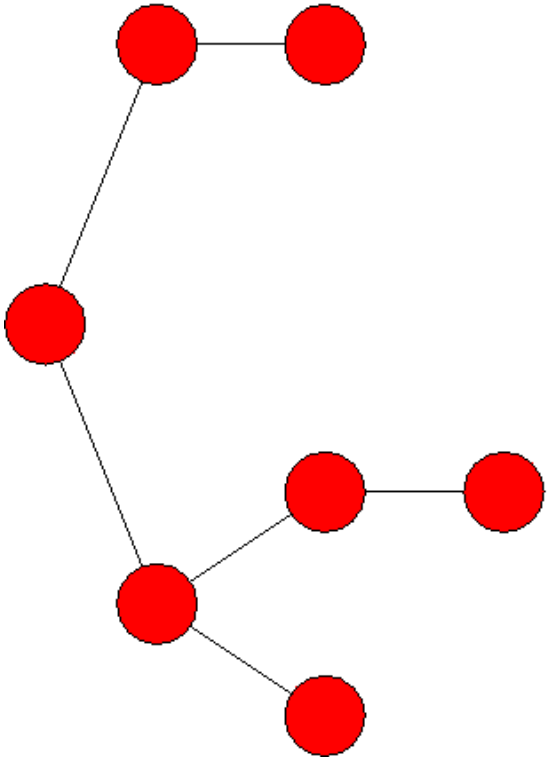
Infectious diseases

A diseased individual passes through
- Incubating period
- Symptomatic period, possibly with a prodrome

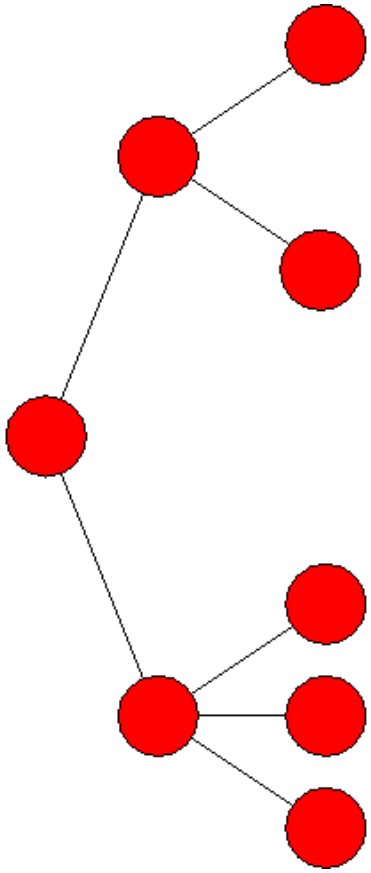
An infectious disease also has
- Latent period
- Infectious period
- Basic reproduction number, R_0



Disease transmission



Short lived outbreak

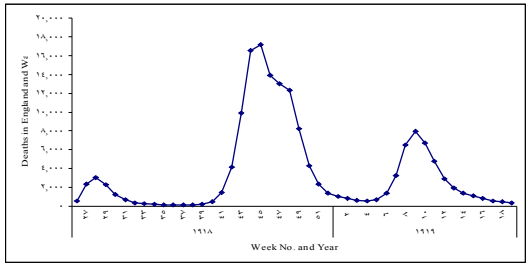


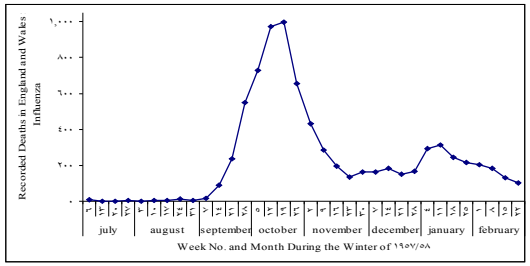
Long lived outbreak

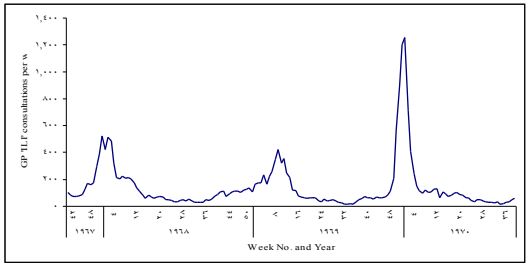
(“epidemic”)

Pandemic influenza

Three pandemics during 20th Century (1918, 1957, 1968)
20 million deaths worldwide in 1918-19







Source: Department of Health

Modelling for future pandemic, assuming

- 2 day latent, 1 day asymptomatic infectious, 1.5 day symptomatic infectious periods
- Basic reproduction number in the range 1.4-2.2
- 25% of UK population show clinical infection with 0.37% case fatality rate
- Excess deaths in the UK of *c.* 50,000

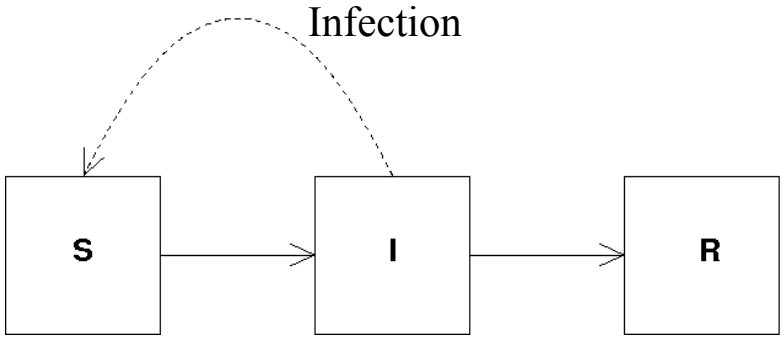
Smallpox

- Eradicated in the wild globally in 1979
- Stockpiles retained in Atlanta, US and Novosibirsk, Russia
- Decreasing immunity in the population
- 12 day latent, 2.5 day prodromal, 8.6 day infectious periods
- 30% case fatality rate
- Basic reproduction number of 5
- Potential to be used in bioterrorism

SIR compartmental model

Population split into three groups

- Susceptible
- Infected
- Removed



Mass action dynamics (Kermack and McKendrick (1927))

$$\frac{dS}{dt} = -\beta \frac{S}{N} I \qquad \frac{dI}{dt} = \beta \frac{S}{N} I - \frac{I}{\tau_1} \qquad \frac{dR}{dt} = \frac{I}{\tau_1}$$

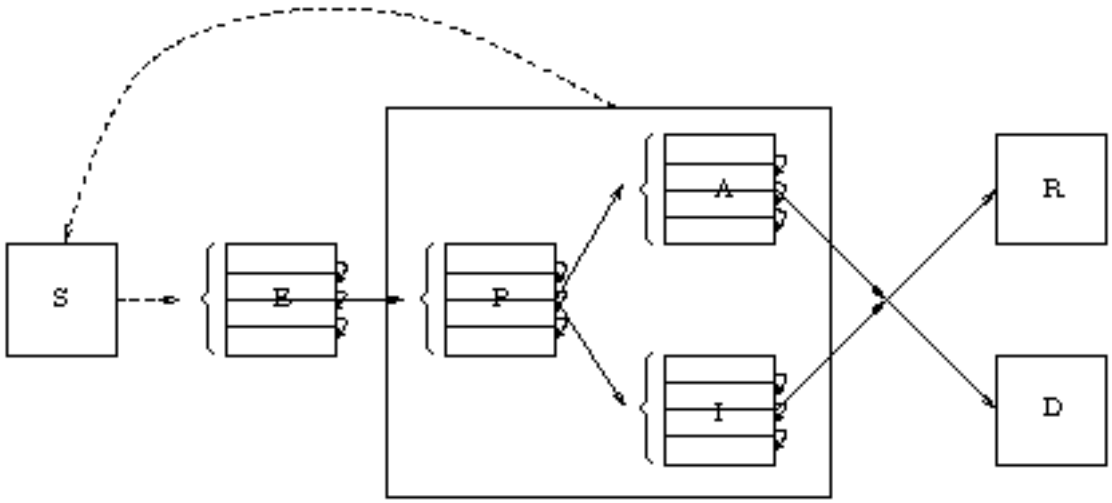
Also can use stochastic transitions

Increasing compartments

Include more disease states than in SIR

- Latent/exposed
- Prodromal
- Asymptomatic infectious
- Dead

Introduce *stage age* (pseudo-individual)

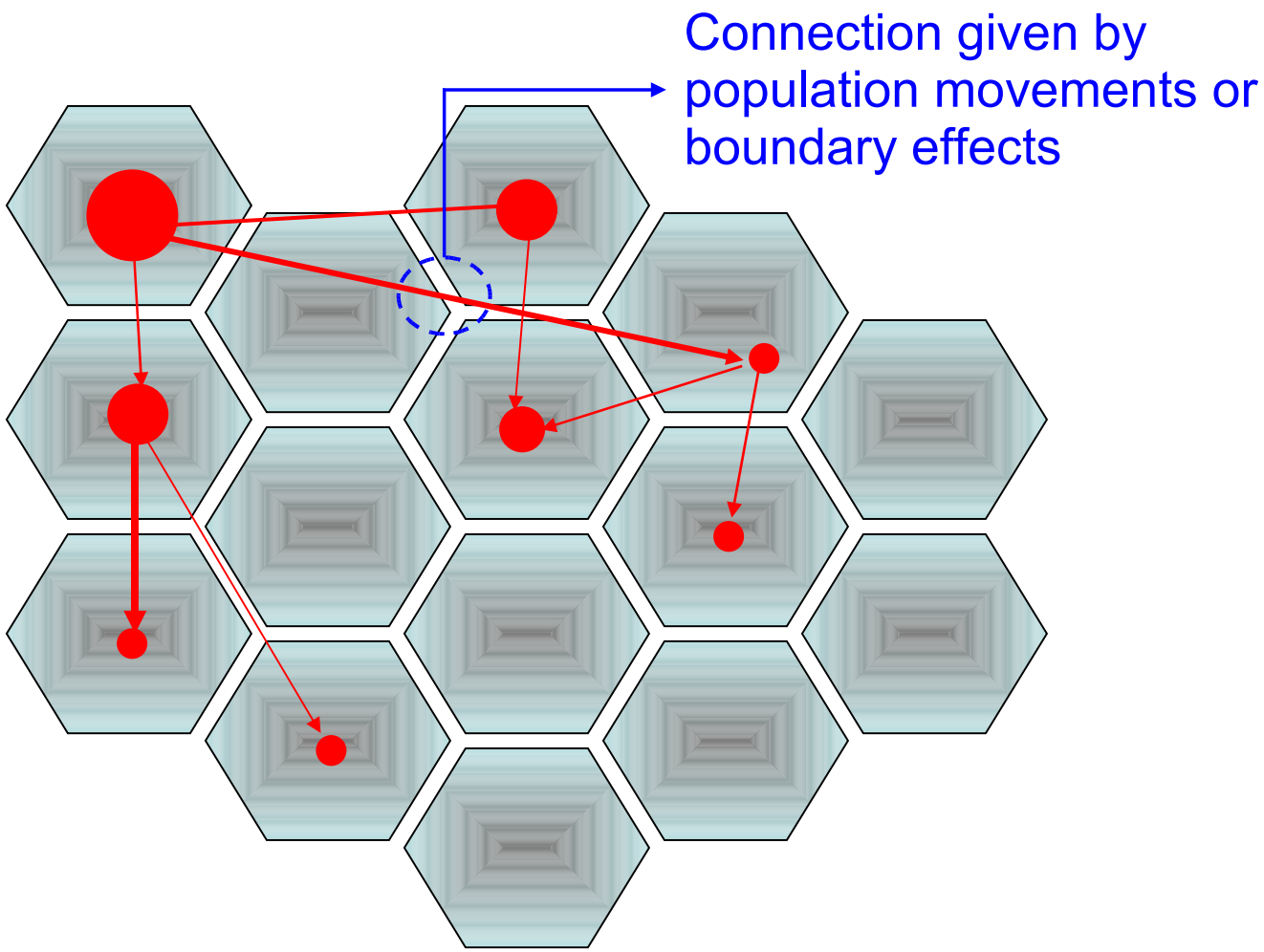


Meta-population models

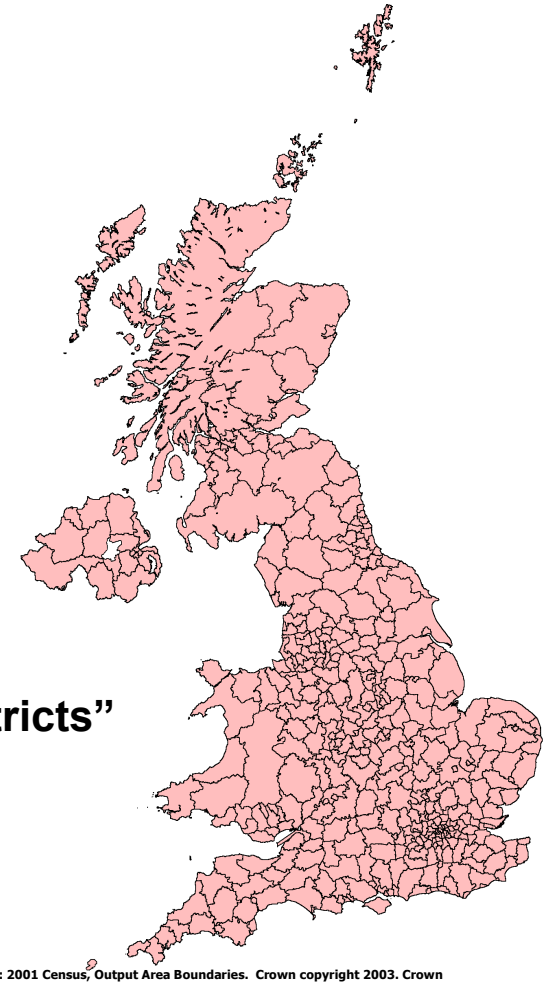
SEIR model within patches

Infection is introduced into one patch

This may infect other patches



Parameterisation



426 “districts”

Source: 2001 Census, Output Area Boundaries. Crown copyright 2003. Crown copyright material is reproduced with the permission of the Controller of HMSO

Describe the UK by administrative regions

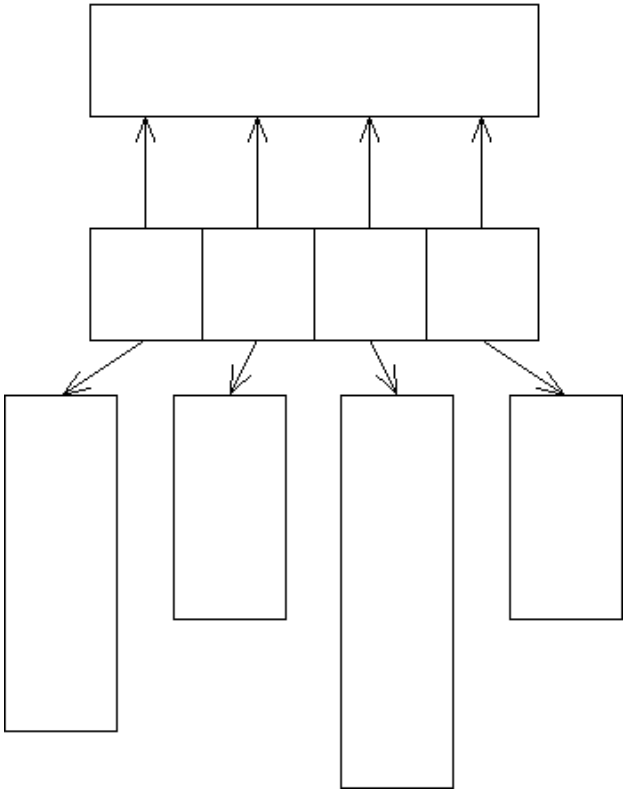
- Electoral wards(10608)
- Districts (426)

2001 Census for

- Populations
- Travel to work

Alternatively, “health geographies”

Patch dynamics



Night time population

Subpopulations

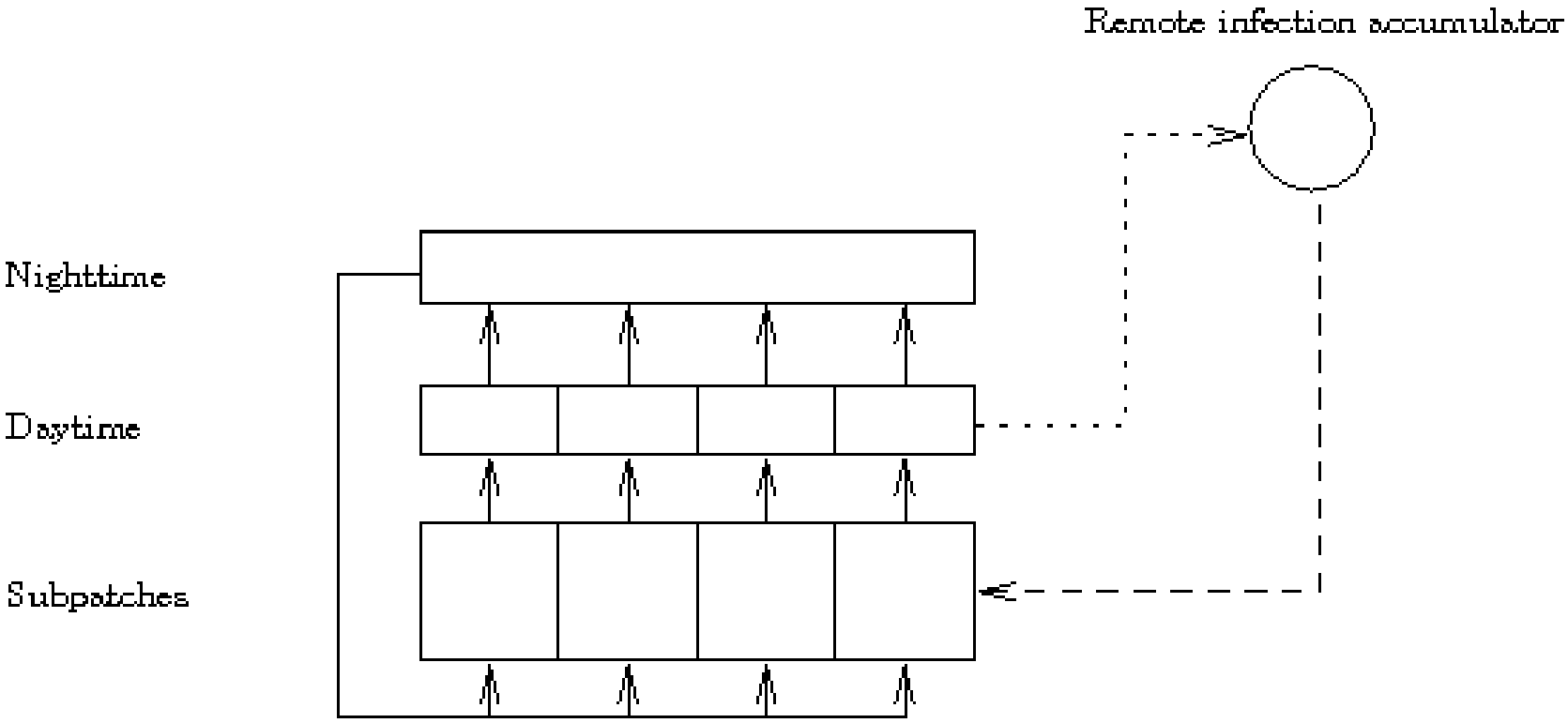
Contribution to force of infection on other patches

Total number of subpatches in the model $O(n^2)$ for n patches

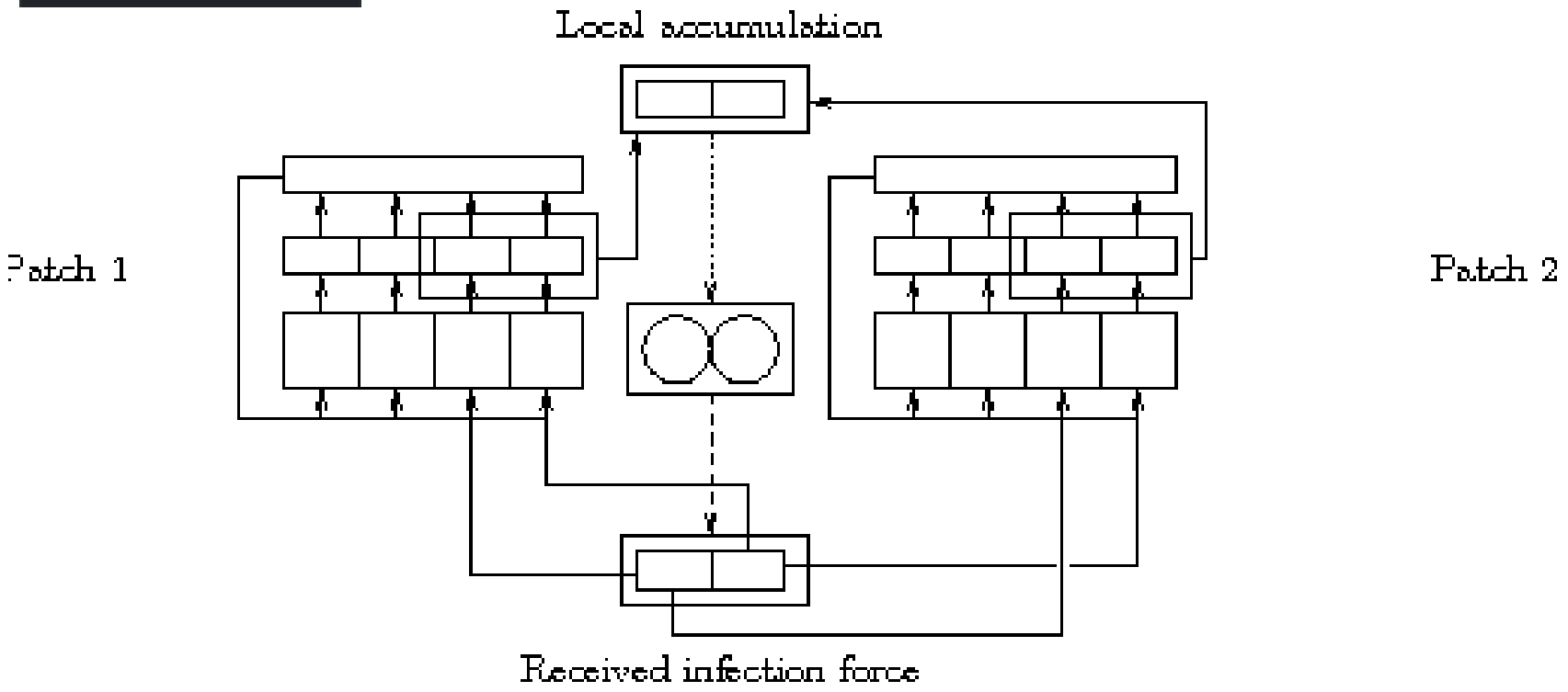
80000 (districts), 1.5 million (wards)

Parallelisation

Single patch on process

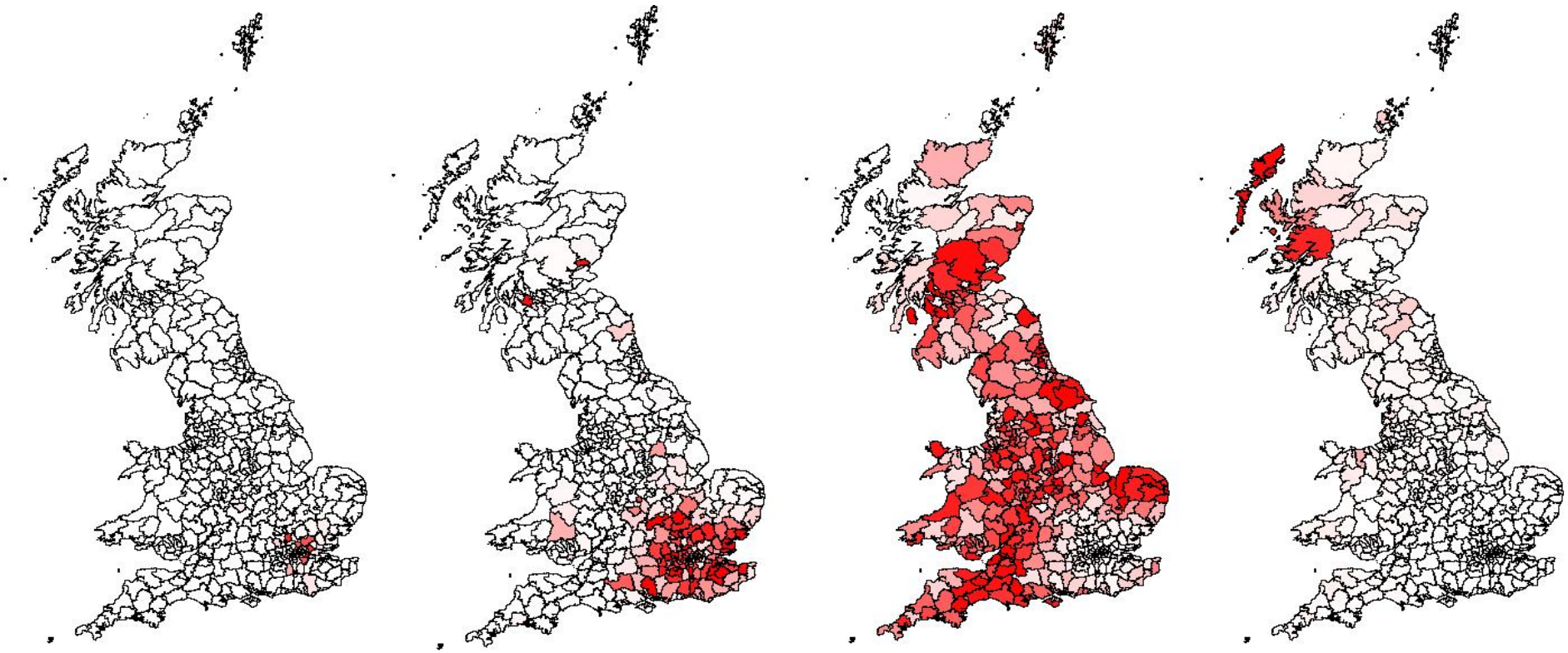


Parallelisation



Two patches of a four patch system held on one process

Spatial spread



Spread of disease away from seed in London

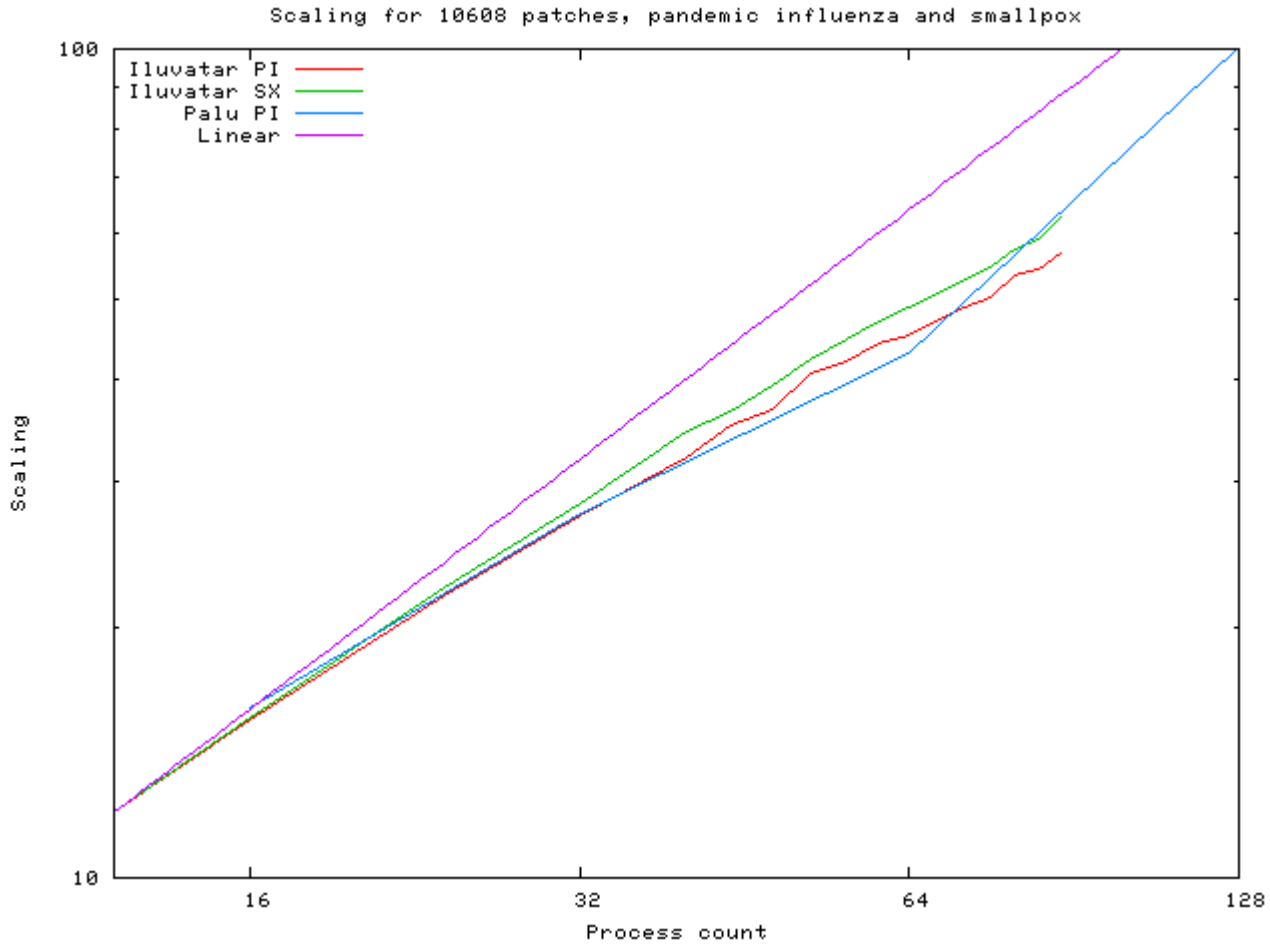
Implementation

Palu – XT3
- 1664 dual-core processors
- 1 GiB memory per core
- SeaStar interconnect

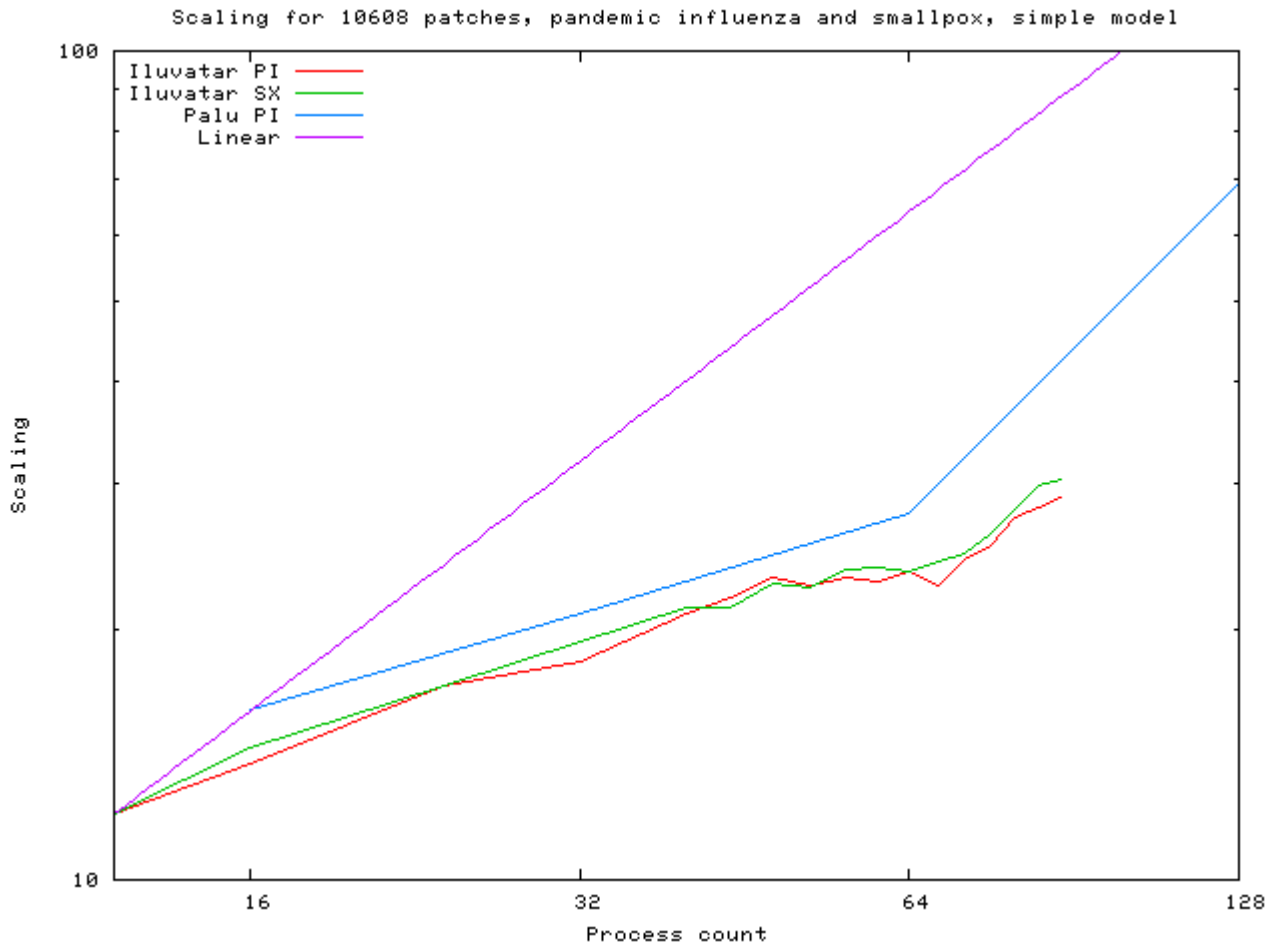
Iluvatar – Linux cluster
- 88 dual-core processors
- 2 GiB memory per core
- Gigabit Ethernet interconnect

Consider
- Simple and pseudo-individual models
- Pandemic influenza and smallpox
- 10608 and 426 patches

Scalability - Pseudo-individual



Scalability - Simple



Conclusions and further work

- Scaling at large problem sizes is good on both machines
- Palu offers good scaling to large process counts
- Problem size increases when consider Europe or the world
- Scaling for smaller problems has possibilities for response

- Dynamic load balancing will improve scaling
- Model complexity can be increased

Acknowledgments

- Kevin Roy (Manchester Computing)
- Steve Leach and Ian Hall (HPA)
- CSCS
- EPSRC