Applications of Exascale Agent-based Modelling: Predicting Migration Patterns and Infectious Diseases

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Content

- Agent-based simulation applications:
  - Conflict-driven forced displacement (Flee)
  - Disaster-induced displacement (DFlee)
  - Flu and Coronavirus Simulator (FACS)
- Three-pronged attack to achieve exascale
- Summary

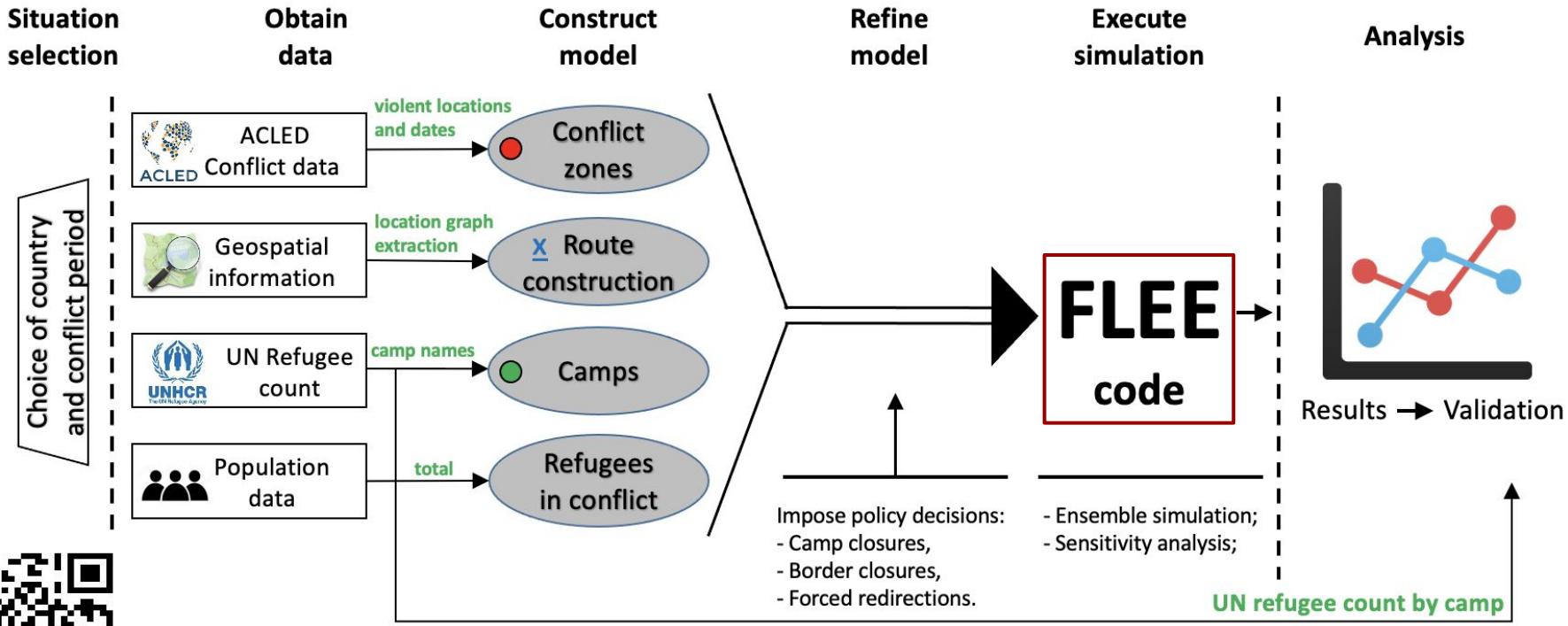
Modelling conflict-driven displacement

Motivation:

- Conflict erupts, people flee
    - Where do they go?
- Can predicting their arrival help organisations to effectively allocate support in advance?
- How do humanitarian decisions affect them?
    - Border closure.
    - Camp placement.
- Better understand historical processes.
- Inform decision-making, and possibly public awareness.

1st paper: Groen, D., 2016. Simulating refugee movements: Where would you go?. *Procedia Computer Science*, *80*, pp.2251-2255.

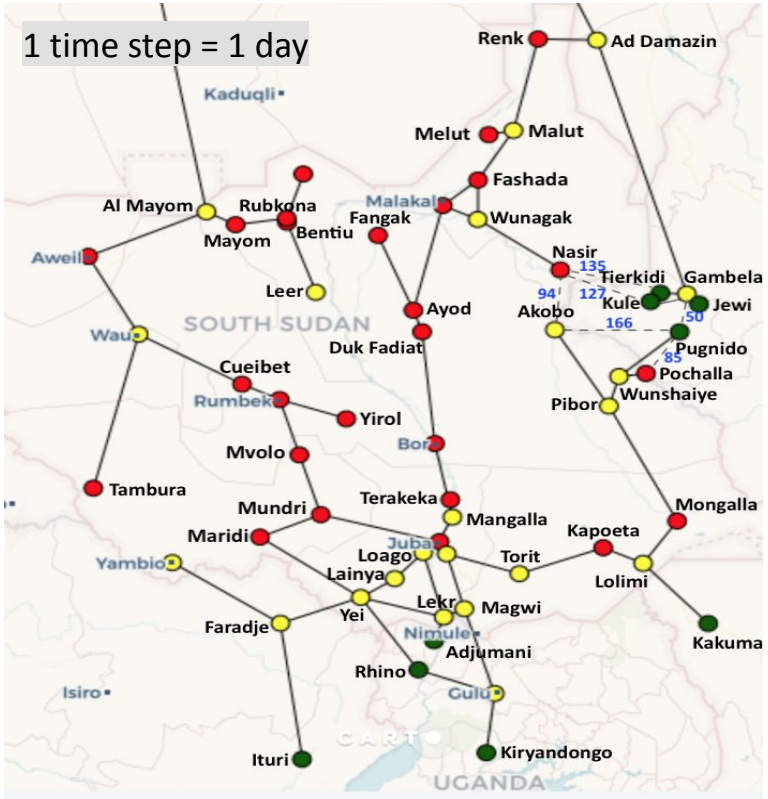
Flee Simulation Development Approach



Suleimenova, D., Bell, D. & Groen, D. A generalized simulation development approach for predicting refugee destinations. *Sci Rep* 7, 13377 (2017)

Introducing Flee

- Agent-based model for forecasting conflict-driven displacement.
- Predicts where people may go, given a developing conflict.
- Existing models for 13 historical conflicts offer a starting point.
- Open source, explicit assumptions.
- https://flee.readthedocs.io



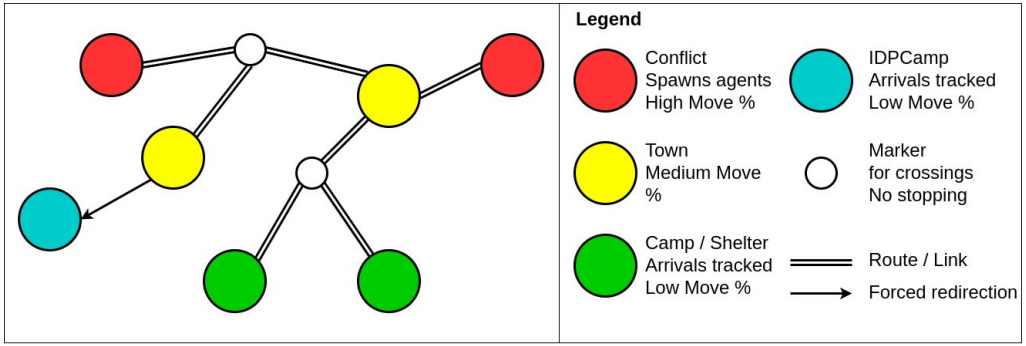
Initial Code: Suleimenova, D., Bell, D. & Groen, D. A generalized simulation development approach for predicting refugee destinations. *Sci Rep* 7, 13377 (2017).

Forecasting challenge: Groen, D., Suleimenova, D., Jahani, A. and Xue, Y. Facilitating simulation development for global challenge response and anticipation in a timely way. Journal of Computational Science, 72, p.102-107 (2023).

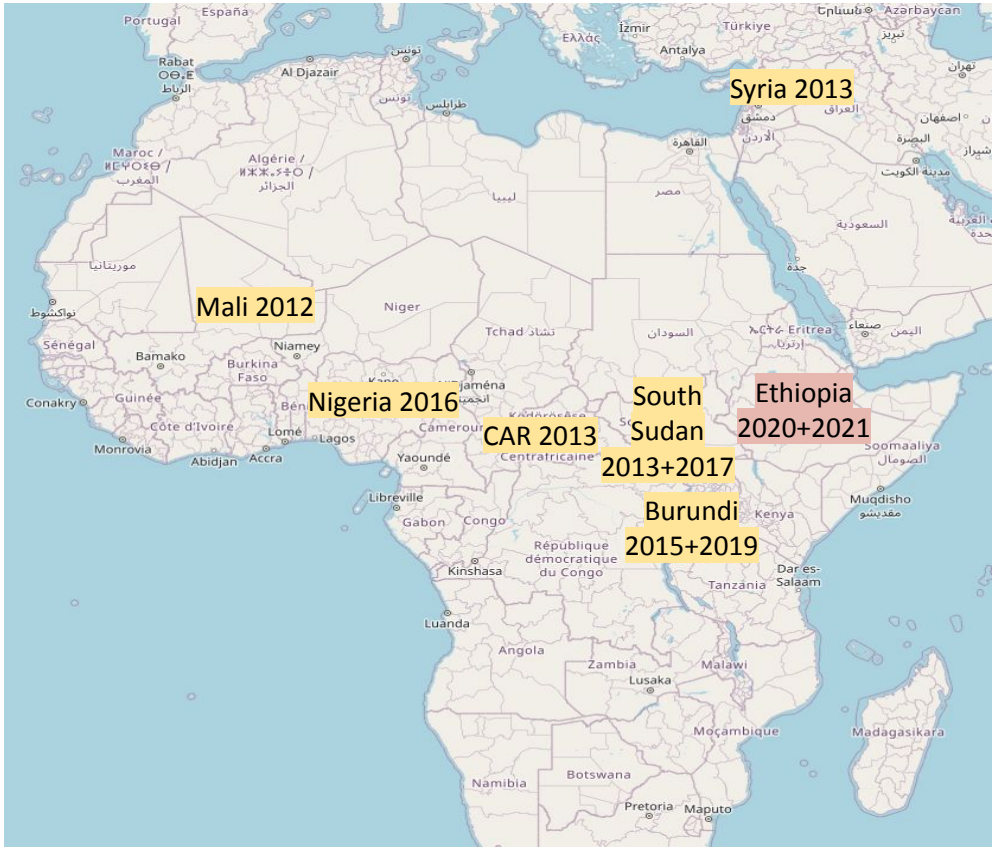
Basics of the logic

FLEE

- Each agent = 1 displaced person.
  - Placed in a conflict zone, will move around in search of a camp.
- Each agent decides:
  - Do I stay put, or move to a neighbouring location?
  - If I move, which location shall I go to?
- Factors such as distance, perceived safety, ethnic match, distance from home can be introduced to shape the decisions.



Main simulations so far



UNHCR The UN Refugee Agency

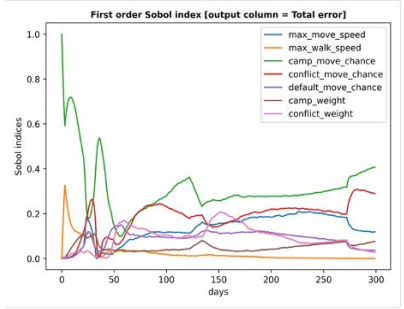
Save the Children

IOM UN MIGRATION

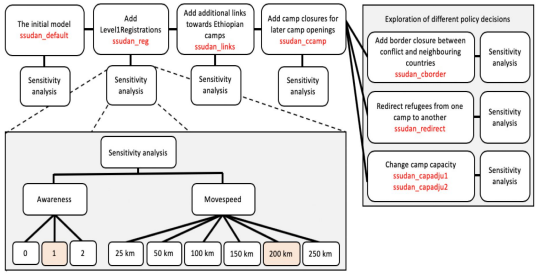
We validated our approach against refugee registration data from UNHCR, and we able to predict >75% of the arrivals correctly across four conflicts.

FabSim3

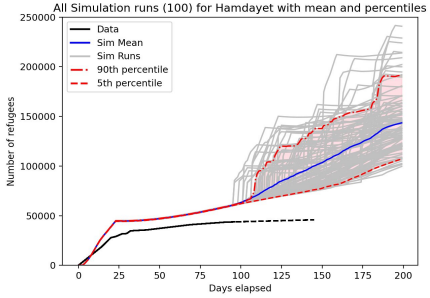
Automated sensitivity analysis



Ensemble models

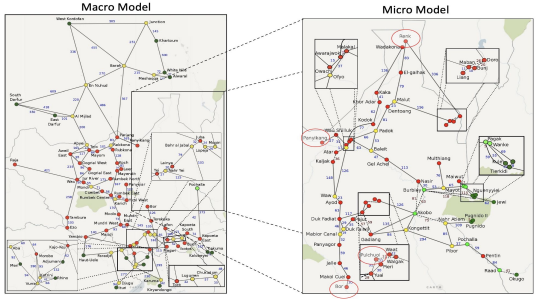


Forecast modelling

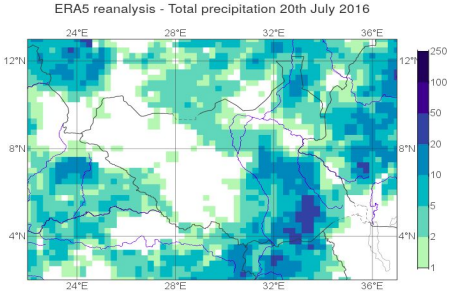


Our Focus

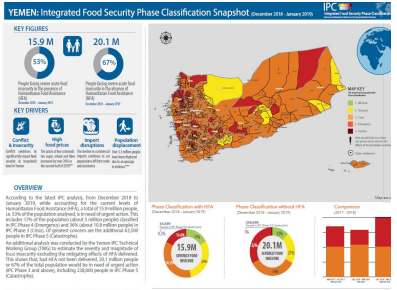
Coupling Macro-Micro



Coupling with weather data

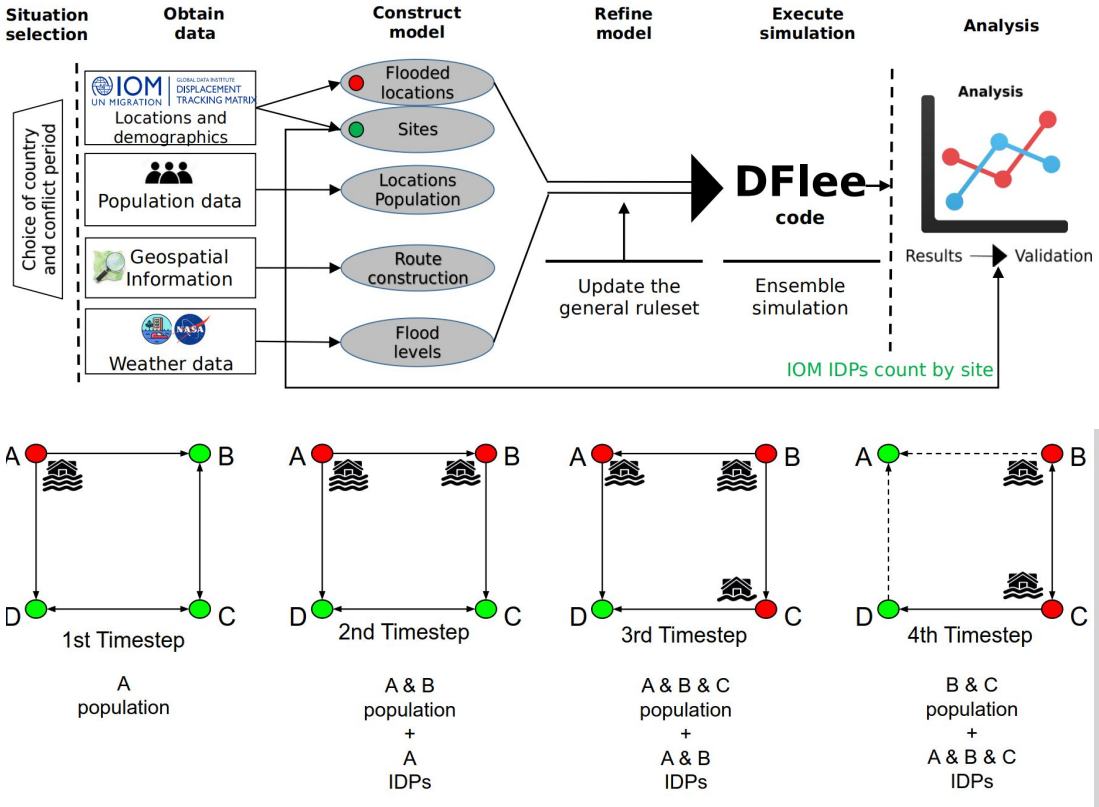


Coupling with food security



Disaster-induced displacement

- We investigate the movement of IDPs during a flood event in small regions rather than large regions and countries.
- Despite similarities between conflicts and disasters, there are some differences in terms of simulation settings, ruleset and destinations between the two events.
- An extension of the Flee code.
- Considering health facilities in route selection decision-making is very important as many of such facilities can temporarily shelter the evacuated people.



Flu and Coronavirus Simulator (FACS)

- Decision-makers need reliable and reproducible forecasts of the spread of COVID-19 in local regions.

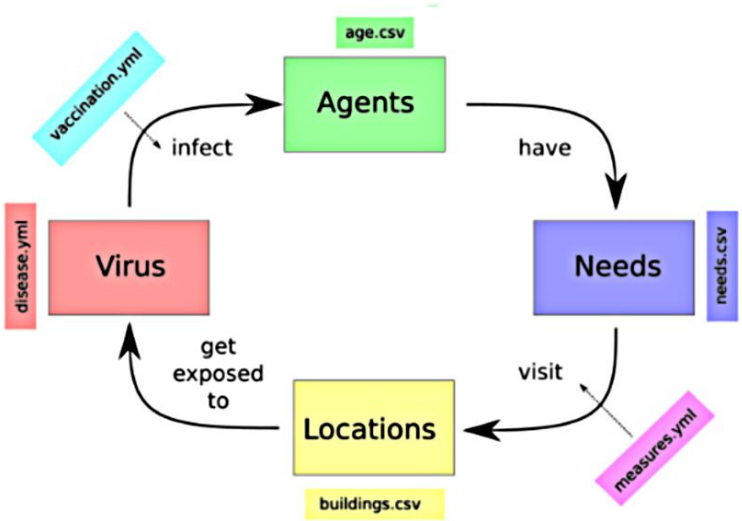
So we established a local collaboration, with volunteers in the Department combined with some redirected effort from the HiDALGO EU Horizon project.

Our aim is to support:

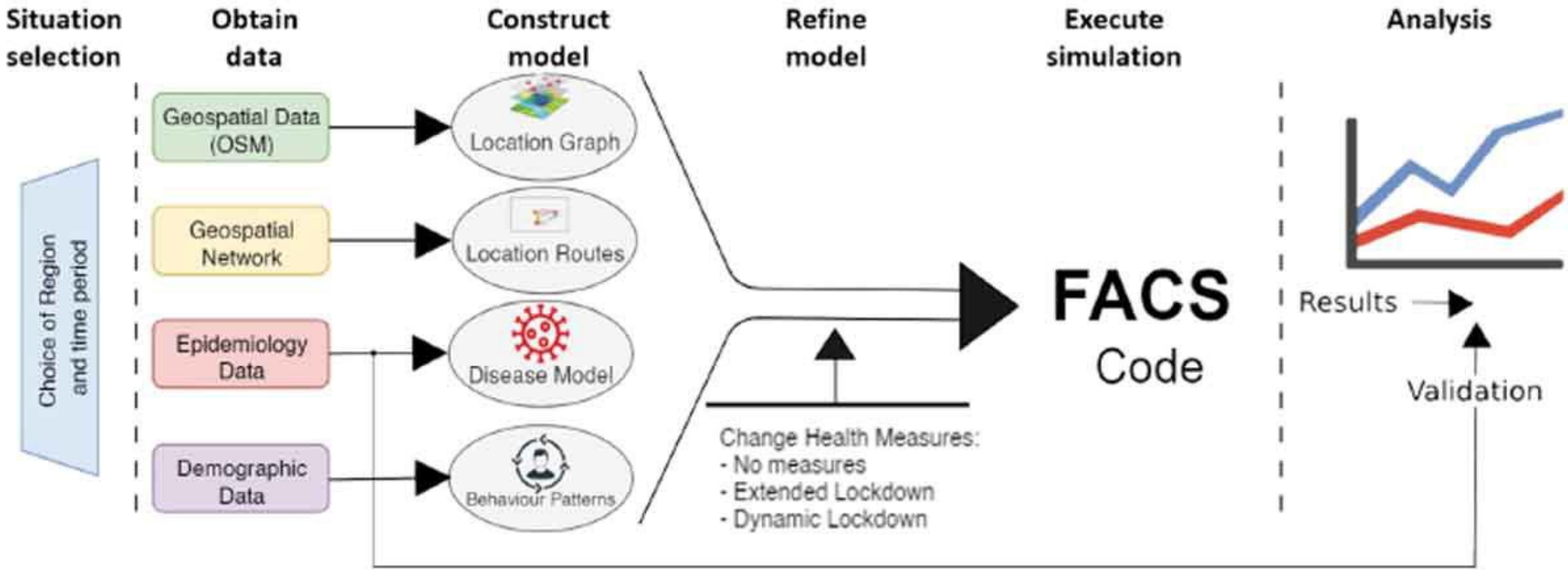
- different lockdowns and other interventions,
- different viral strains,
- and later: different vaccination efficacies and strategies.

... on the hyperlocal sub-national level.

https://facs.readthedocs.io

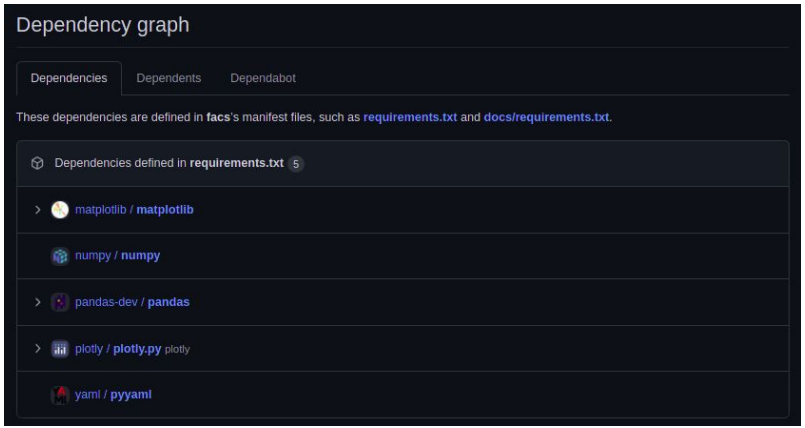


FACS Simulation Development Approach

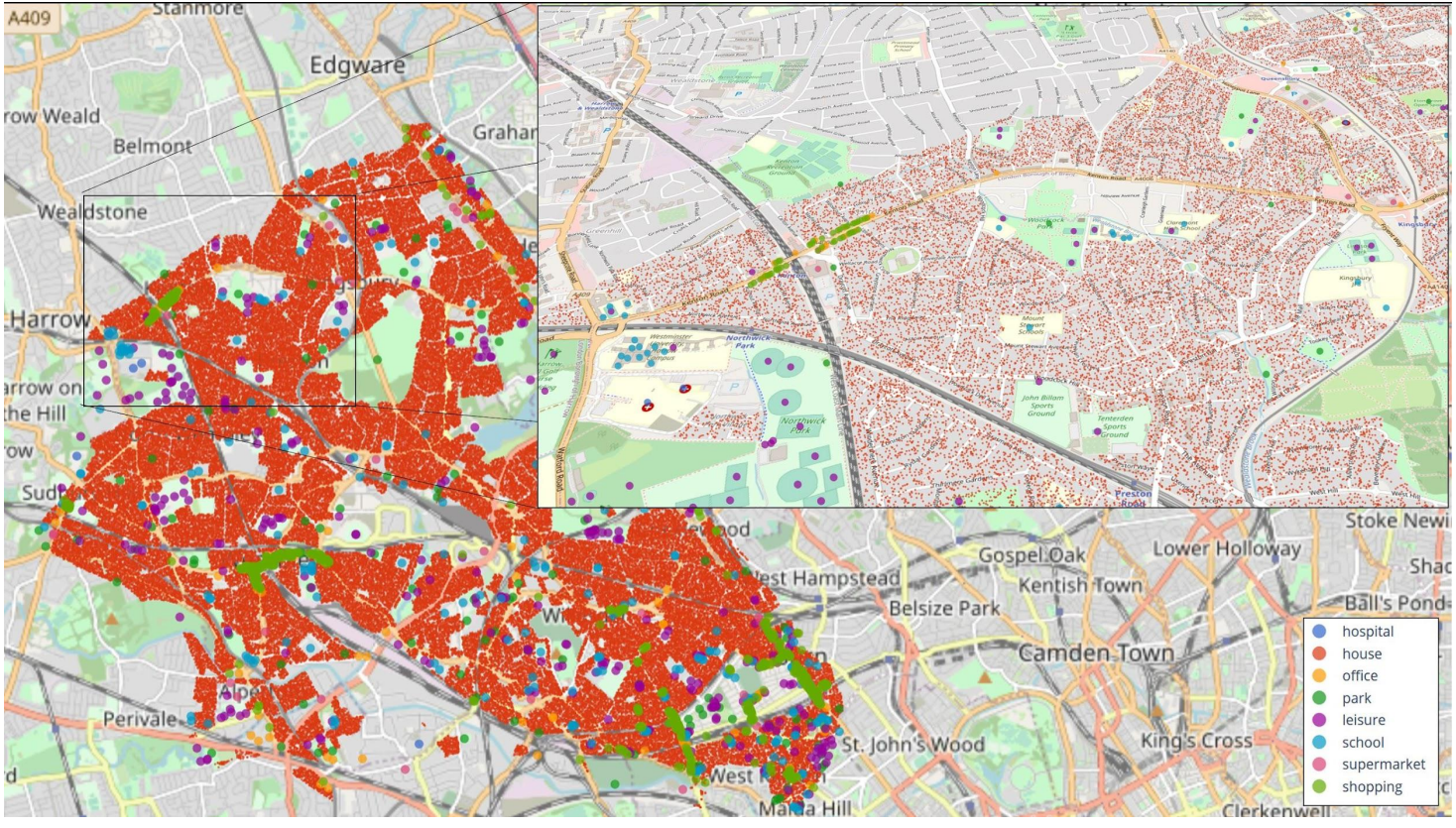


FACS code

- Written in Python 3.
- Single runs support up to 1M households.
- Runtime: 1-8 hours
- FACS can efficiently run in parallel, using up to ~128 cores.
- Applications:
  - W. London NHS Trusts (13 forecasting reports),
  - UK Trial with Health Security Agency,
  - Lithuania, Turkey, Romania.



Example input: Location graph



Measures: Non-pharmaceutical Interventions

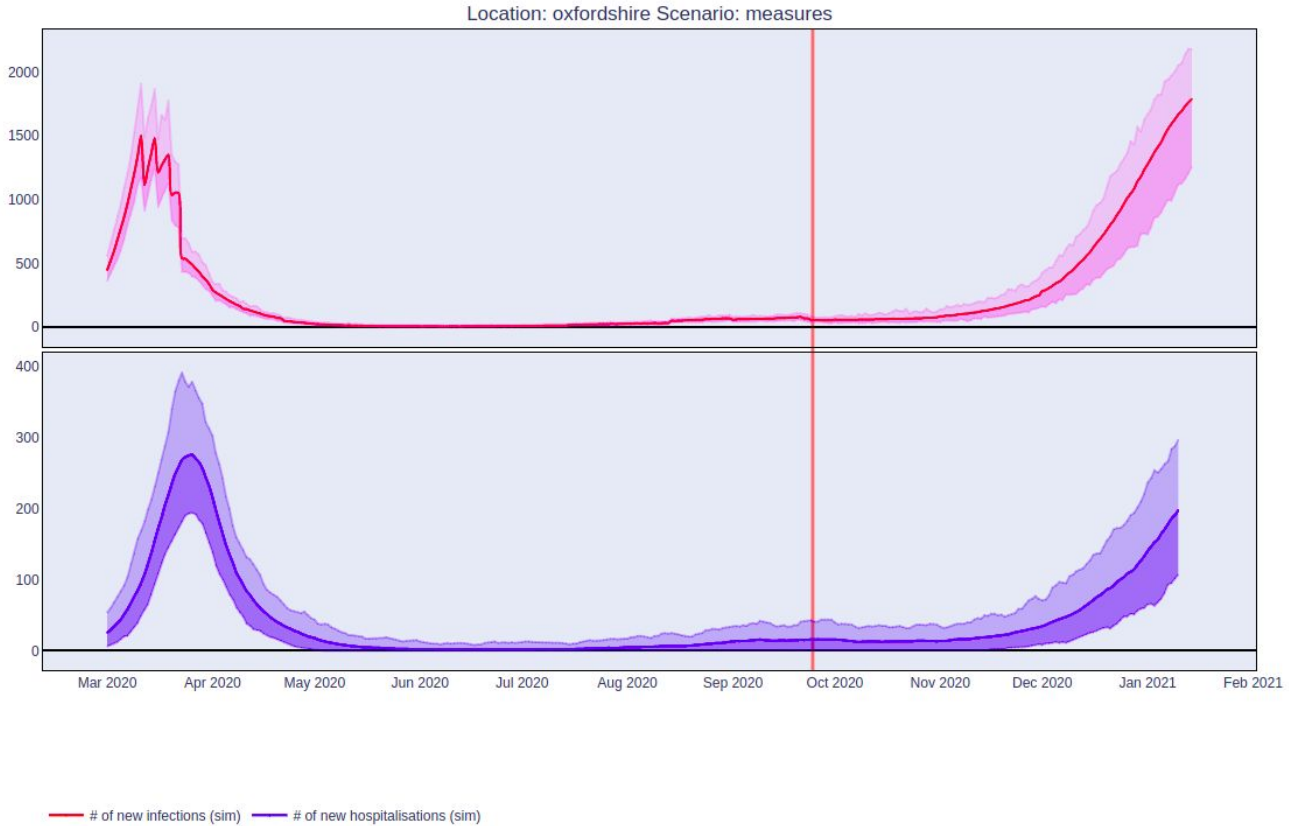
- Timeline of lockdown measures and closures provided in a yaml file

Table 1. Summary of lockdown measures implemented during the simulation.

Date	Days since start of simulation	Lockdown Measures
March 01, 2020	0	Start of simulation
March 21, 2020	20	First lockdown
April 22, 2020	52	Peak of lockdown measures
September 01, 2020	184	Schools re-opening
November 05, 2020	249	Second lockdown
December 02, 2020	276	Restrictions lifted
December 23, 2020	297	Christmas bubble
January 06, 2021	311	Third lockdown
March 08, 2021	372	Restrictions lifting
April 04, 2021	399	End of simulation

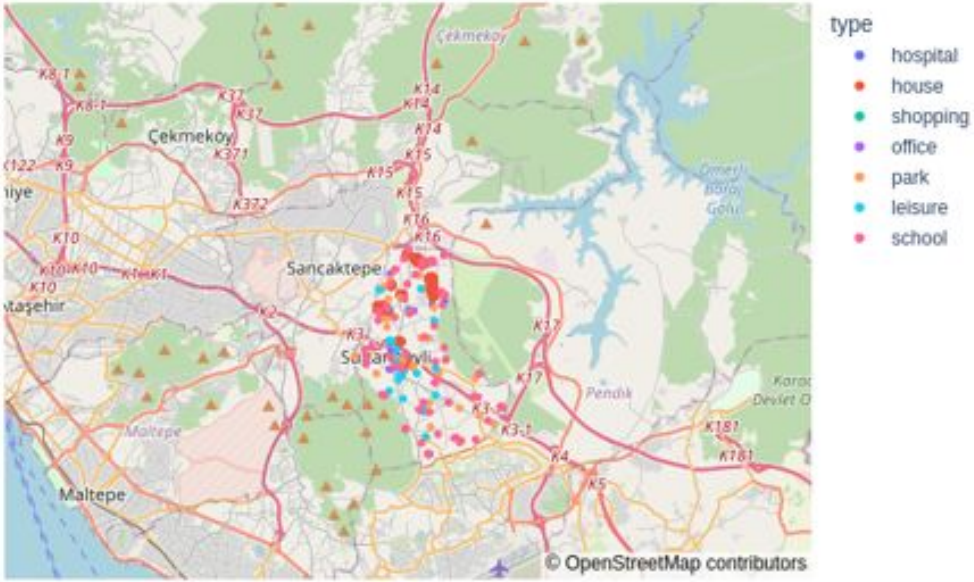
```yaml
1/3/2020:
  traffic_multiplier: 0.8
12/3/2020:
  work_from_home: 0.1
  social_distance: 0.1
  traffic_multiplier: 0.5
16/3/2020:
  partial_closure:
    leisure: 0.3
  work_from_home: 0.325 #assumption is that uptake between 11 and 21 Mar is gradual
  social_distance: 0.25 #assumption is that uptake between 11 and 21 Mar is gradual
  mask_uptake: 0.05
  traffic_multiplier: 0.4
20/3/2020:
  closure: ["leisure"]
  work_from_home: 0.45 #assumption is that uptake between 11 and 21 Mar is gradual
  social_distance: 0.5 #assumption is that uptake between 11 and 21 Mar is gradual
  mask_uptake: 0.05
  traffic_multiplier: 0.3
23/3/2020:
  partial_closure:
    school: 1.0
    shopping: 0.7 #indicates full school closure, but partial_closure is used to allow keyworkers to be added.
  closure: ["leisure"]
  social_distance: 0.75
  mask_uptake: 0.05
  mask_uptake_shopping: 0.1
  work_from_home: 1.0
  traffic_multiplier: 0.25
22/4/2020:
  partial_closure:
    school: 1.0
    shopping: 0.8
  closure: ["leisure"]
```

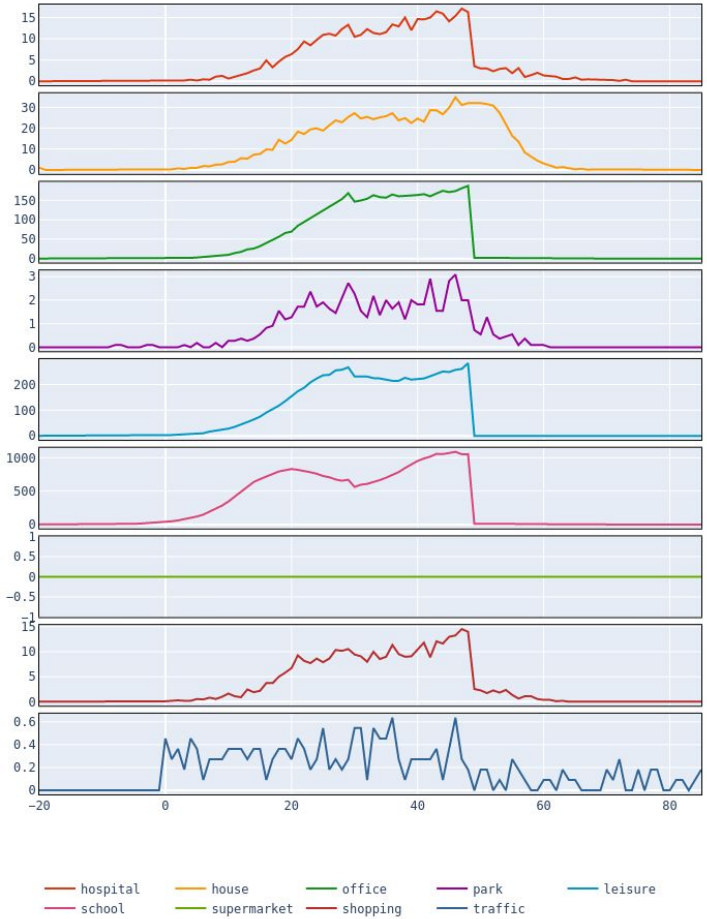
Example result: Oxfordshire Tier-2 (100 run ensemble)



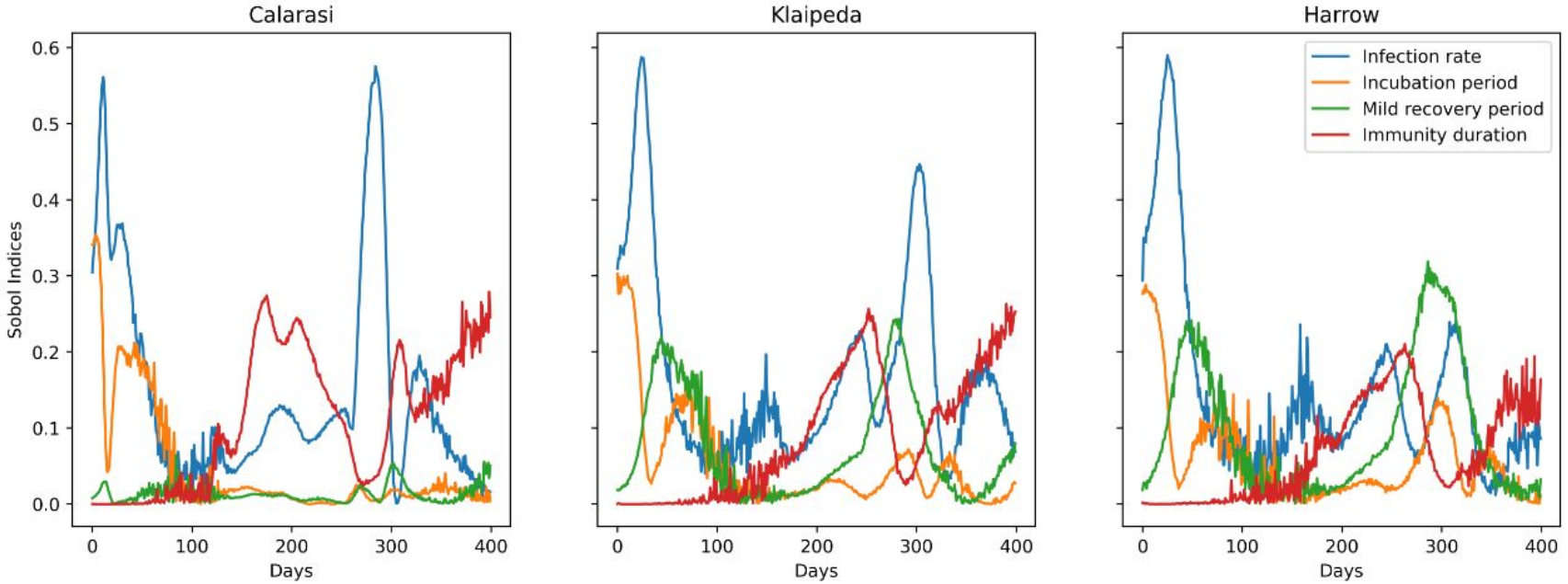
Granular Details of Infections

- Building types where most infections take place.
- Geographical hot-spots as a function of time.



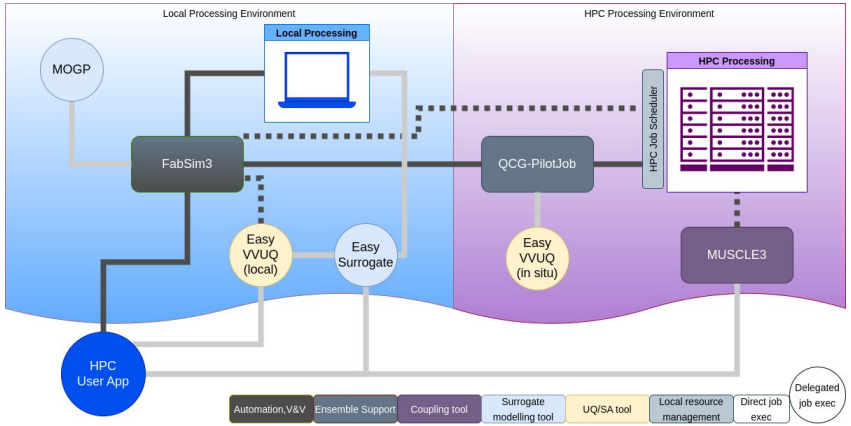


Sensitivity Analysis: Impact of Geography on



Need for Exascale Computing in FACS

- Sensitivity Analysis
  - Disease parameters
  - Demographic characteristics
  - Interventions
- Multi-scalability
  - ‘Large-picture’ analysis - nation-wide predictions
  - Detailed granularity - admissions in a particular hospital
- Coupling with other simulations
  - UM - Impact of climate on infectious diseases
  - CHARM - Modifications to hospital bed management



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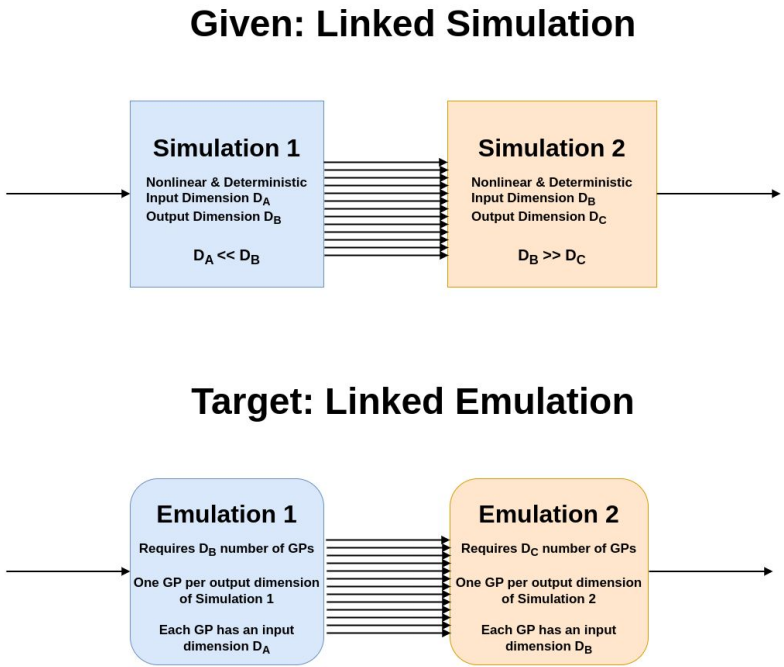
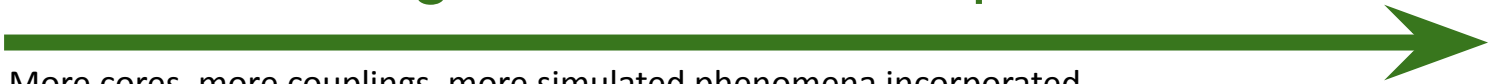


Three-pronged attack to achieve exascale

- Parallelizing/enhancing single scale models.

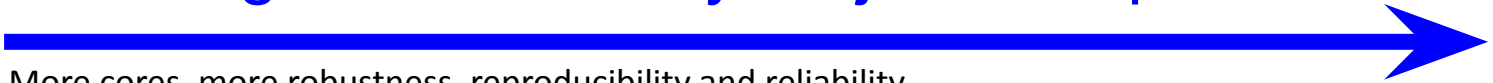
More cores, faster time to completion.

- Constructing multi-scale / coupled models.



More cores, more couplings, more simulated phenomena incorporated.

- Adding VVUQ + *Many*-Objective Optimisation



More cores, more robustness, reproducibility and reliability.

Summary

- Active modelling efforts:
  - Flee, DFlee and FACS
    - Improving the quality of our models by validating settings.
    - Search for optimal configurations to model different scenarios.
    - Sensitivity analysis: testing which assumptions matter most.
- Collaborations and projects

SEAVEA

IOM UN MIGRATION

UNHCR The UN Refugee Agency United Kingdom for UNHCR

Columbia University

Georgetown University

Save the Children

Upcoming events

- The ExCALIBUR Workshop on Exascale Computing @ ICCS.
  - https://excalibur.ac.uk/events/iccs-excalibur-day
  - 1 July 2024, Malaga, Spain.
  - Register for the ExCALIBUR Workshop via the ICCS EasyChair registration process.

Questions?

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