

Appendix Section

(For text:

Sample computational structures towards an epidemic simulation tool comprising communicating programs on mobile phones and servers

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Appendix

A. Additional Example Results

Continuing with the example results from the Phase 2/2A program, here is an excerpt from the detailed longitudinal manuscript (output used for testing) of the SimAnalog humans interacting:

...

I, clock, just ticked on day 55.

I, SimAnalog human number 1, am responding with state to the tick of the clock on day 55.

I, SimAnalog human number 2, am responding with state to the tick of the clock on day 55.

I, SimAnalog human number 3, am responding with state to the tick of the clock on day 55.

...

I, SimAnalog human number 151, am responding with action at morning/afternoon-time location indexed 26 to the tick of the clock on day 66.

I, SimAnalog human number 151, would like to interact now on day 66.

I, SimAnalog human number 151, am attempting to initiate an interaction on day 66.

I, SimAnalog human number 151 along with SimAnalog human number 78 are implicitly interacting on day 66.

I, SimAnalog human number 152, am responding with action at morning/afternoon-time location indexed 29 to the tick of the clock on day 66.

I, SimAnalog human number 152, would like to interact now on day 66.

I, SimAnalog human number 152, am attempting to initiate an interaction on day 66.

I, SimAnalog human number 152 along with SimAnalog human number 283 are implicitly interacting on day 66.

...

I, SimAnalog human number 24, am responding with action at evening/night-time location indexed 65 to the tick of the clock on day 87.

I, SimAnalog human number 24, would like to interact now on day 87.

I, SimAnalog human number 24, am attempting to initiate an interaction on day 87.

I, SimAnalog human number 24 along with SimAnalog human number 220 are implicitly interacting on day 87.

...

I, SimAnalog human number 185, am responding with action at evening/night-time location indexed 75 to the tick of the clock on day 44.

I, SimAnalog human number 185, would like to interact now on day 44.

I, SimAnalog human number 185, am attempting to initiate an interaction on day 44.

I, SimAnalog human number 185 along with SimAnalog human number 192 are implicitly interacting on day 44.

I, SimAnalog human number 186, am responding with action at evening/night-time location indexed 90 to the tick of the clock on day 44.

I, SimAnalog human number 186, would like to interact now on day 44.

I, SimAnalog human number 186, am attempting to initiate an interaction on day 44.

I, SimAnalog human number 186 along with SimAnalog human number 239 are implicitly interacting on day 44.

...

I, central parameters and data, during (SimAnalog) simulation titled TestDetailedLocnCategsWGenlPreventnOpt am responding to the tick of the clock on day 90.

...

Here is an excerpt from the detailed longitudinal manuscript from one of the SimAnalogSims (simulation within a simulation; i.e. epidemic simulation) which shows that a day 44 interaction between SimAnalog humans 186 & 239 seen in an excerpt above then, within SimAnalogSim 2, stochastically led to a corresponding Sim human interaction which then stochastically led to an infection transmission whereas the interaction between SimAnalog humans 185 and 192 did not lead to a corresponding Sim human interaction:

...

[day 44]

I, SimAnalogSim human, associated with SimAnalog human number 184 & SimAnalogSim number 2, am responding with state to a message about the tick of the clock on day 44.

I, SimAnalogSim human, associated with SimAnalog human number 185 & SimAnalogSim number 2, am responding with state to a message about the tick of the clock on day 44.

I, SimAnalogSim human, associated with SimAnalog human number 186 & SimAnalogSim number 2, am responding with state to a message about the tick of the clock on day 44.

I, SimAnalogSim human, associated with SimAnalog human number 186 & SimAnalogSim number 2, just became infectious on day 44.

I, SimAnalogSim human, associated with SimAnalog human number 186 & SimAnalogSim number 2, am infectious on day 44.

I, SimAnalogSim human, associated with SimAnalog human number 186 & SimAnalogSim number 2, am infectious & interacting on day 44.

I, SimAnalogSim human, associated with SimAnalog human number 187 & SimAnalogSim number 2, am responding with state to a message about the tick of the clock on day 44.

...

[day 44]

I, SimAnalogSim human, associated with SimAnalog human number 182 & SimAnalogSim number 2, am interacting with SimAnalogSim human, associated with SimAnalog human number 226 & SimAnalogSim number 2.

I, SimAnalogSim human, associated with SimAnalog human number 226 & SimAnalogSim number 2, am interacting with SimAnalogSim human, associated with SimAnalog human number 182 & SimAnalogSim number 2.

I, SimAnalogSim human, associated with SimAnalog human number 186 & SimAnalogSim number 2, am interacting with SimAnalogSim human, associated with SimAnalog human number 239 & SimAnalogSim number 2.

I, SimAnalogSim human, associated with SimAnalog human number 239 & SimAnalogSim number 2, am interacting with SimAnalogSim human, associated with SimAnalog human number 186 & SimAnalogSim number 2.

I, SimAnalogSim human, associated with SimAnalog human number 239 & SimAnalogSim number 2, have been infected by SimAnalogSim human, associated with SimAnalog human number 186 & SimAnalogSim number 2 at evening/night-time location indexed 90.

I, SimAnalogSim human, associated with SimAnalog human number 187 & SimAnalogSim number 2, am interacting with SimAnalogSim human, associated with SimAnalog human number 261 & SimAnalogSim number 2.

I, SimAnalogSim human, associated with SimAnalog human number 261 & SimAnalogSim number 2, am interacting with SimAnalogSim human, associated with SimAnalog human number 187 & SimAnalogSim number 2.

...

[day 45]

I, SimAnalogSim human, associated with SimAnalog human number 238 & SimAnalogSim number 2, am responding with state to a message about the tick of the clock on day 45.

I, SimAnalogSim human, associated with SimAnalog human number 239 & SimAnalogSim number 2, am responding with state to a message about the tick of the clock on day 45.

I, SimAnalogSim human, associated with SimAnalog human number 239 & SimAnalogSim number 2, am incubating an infection on day 45.

I, SimAnalogSim human, associated with SimAnalog human number 240 & SimAnalogSim number 2, am responding with state to a message about the tick of the clock on day 45.

I, SimAnalogSim human, associated with SimAnalog human number 241 & SimAnalogSim number 2, am responding with state to a message about the tick of the clock on day 45.

I, SimAnalogSim human, associated with SimAnalog human number 242 & SimAnalogSim number 2, am responding with state to a message about the tick of the clock on day 45.

I, SimAnalogSim human, associated with SimAnalog human number 243 & SimAnalogSim number 2, am responding with state to a message about the tick of the clock on day 45.

I, SimAnalogSim human, associated with SimAnalog human number 244 & SimAnalogSim number 2, am responding with state to a message about the tick of the clock on day 45.

I, SimAnalogSim human, associated with SimAnalog human number 244 & SimAnalogSim number 2, am immune on day 45.

I, SimAnalogSim human, associated with SimAnalog human number 245 & SimAnalogSim number 2, am responding with state to a message about the tick of the clock on day 45.

...

Excerpt mentioned in main text from Phase 3 results:

This is what analog human # 294 views on its smart device as information about its Sim Human for infection simulation # 2.

Basic info on infection simulation # 2: indicator (1 or 0) whether want to start epidemic in population: 1, by starting with this # of infectious humans: 3 with this proportion of population in some general transmission (partial) prevention mode: 0.5.

To view the aggregated simulated population infection data, use your smart device to view/access that data from the central computer. Here, you can view details on your individual Sim Human for this infection simulation.

Your individual sim human for this infection simulation is **in general transmission prevention mode, meaning that it has a reduced probability of interaction -- reduced compared to how your smart device interprets/estimates/simulates your possible interactions from information communicated from other nearby smart devices.**

At the beginning -- initial conditions -- of this infection simulation, your individual sim human is susceptible/not-infected-&-not-immune.

Day 1

Day 2

...

Day 30

I'm interacting in the evening/night at location category evening/night&weekendmorning/afternoon indexed 20.

I have been infected in the evening/night at location category evening/night&weekendmorning/afternoon indexed 20. The incubation period has started. The human who infected me was in general transmission prevention mode.

Day 31

I'm interacting in the morning/afternoon at location category weekdaymorning/afternoon indexed 5.

Day 32

...

Day 35

I just became infectious. I'm still interacting for now.

Day 36

I'm interacting in the morning/afternoon at location category weekdaymorning/afternoon indexed 5.

I'm interacting in the evening/night at location category evening/night&weekendmorning/afternoon indexed 20.

Day 37

I'm interacting in the morning/afternoon at location category weekdaymorning/afternoon indexed 5.

I'm interacting in the morning/afternoon at location category weekdaymorning/afternoon indexed 5.

Day 38

Day 39

Day 40

I'm still infectious, but I'm now also refraining from interacting.

Day 41

...

This is what analog human # 294 views on its smart device as information about its interpreted analog human -- the smart device's interpretation of its location and simulated interactions interpreted as possible based on spatial interpreted & sim human info communicated to a central computer by other smart devices in vicinity. Other smart devices are not distinguished from each

other in the record here other than instantaneous spatial info (for the simulated infections elsewhere, instantaneous spatial info on smart device sim human infections & transmission prevention measures may be processed & recorded, but other than this again smart devices are not distinguished from each other).

Day 1

I'm interacting with someone in the morning/afternoon at location category weekdaymorning/afternoon indexed 5.

I'm interacting with someone in the evening/night at location category evening/night&weekendmorning/afternoon indexed 20.

Day 2

...

Day 30

I'm interacting with someone in the morning/afternoon at location category weekdaymorning/afternoon indexed 5.

I'm interacting with someone in the morning/afternoon at location category weekdaymorning/afternoon indexed 5.

I'm interacting with someone in the evening/night at location category evening/night&weekendmorning/afternoon indexed 20.

I'm interacting with someone in the evening/night at location category evening/night&weekendmorning/afternoon indexed 20.

Day 31

I'm interacting with someone in the morning/afternoon at location category weekdaymorning/afternoon indexed 5.

I'm interacting with someone in the morning/afternoon at location category weekdaymorning/afternoon indexed 5.

I'm interacting with someone in the evening/night at location category evening/night&weekendmorning/afternoon indexed 20.

I'm interacting with someone in the evening/night at location category evening/night&weekendmorning/afternoon indexed 20.

Day 32

...

Day 35

I'm interacting with someone in the morning/afternoon at location category evening/night&weekendmorning/afternoon indexed 20.

I'm interacting with someone in the morning/afternoon at location category evening/night&weekendmorning/afternoon indexed 20.

I'm interacting with someone in the morning/afternoon at location category evening/night&weekendmorning/afternoon indexed 20.

I'm interacting with someone in the evening/night at location category evening/night&weekendmorning/afternoon indexed 20.

I'm interacting with someone in the evening/night at location category evening/night&weekendmorning/afternoon indexed 20.

Day 36

I'm interacting with someone in the morning/afternoon at location category weekdaymorning/afternoon indexed 5.

I'm interacting with someone in the evening/night at location category evening/night&weekendmorning/afternoon indexed 20.

I'm interacting with someone in the evening/night at location category evening/night&weekendmorning/afternoon indexed 20.

Day 41

...

Also note that it might also be interesting to view some sample results from the synthetic map, synthetic meta-map, and synthetic data from Phase 4. For all phases, the full code along with some sample results are available as Supplementary Information; sample results generated when the code for a phase is run include files for server displays (and optional mobile device displays) as well as general code-output files (describing/summarizing/tabulating various specific outputs and logs for code testing) showing the epidemic simulation data (collected by a server), optional views of the simulation from individual mobile devices, synthetic meta-map summary descriptions/tables, synthetic map summary descriptions/tables, synthetic data/info of mobile device locations over time, logs to evaluate/test code runs.

B. Phase 1 program structure

Here summarized is the object-oriented program structure for the Phase 1 program Sim which is similar in structure to a typical microsimulation / individual-level model / agent-based model. Note that it uses a sample model rather than a more rigorous model such as is more typically found in the research literature. The roughness of the program is for efficiency while the main purpose is to illustrate the structure of a typical individual-level model so that it can be compared to the program structures of the other phases. Note that for this and all other phases, the files generated by the programs/processes are for output and for testing and/or logging, sometimes large files are generated and sometimes many files are generated.

Run Sim

Main method: interprets user input (# days to run sim, # humans in sim, note that in simple program form # locations of each category is based on # humans, whether to start epidemic and with how many infectious humans at start, title string to use for making files); build (directly or indirectly) objects for simulation; start clock ticking for # days for sim; ...

Central Parameters and Data

Fields/States&ObjectsContained: pointer to clock; parameter values; structures for gathering sim data; for recording data & other sim details; ...

Methods: respond to tick of clock / passage of time; ...

Constructor to Build Instance of Object: ...

Clock

Fields/States&ObjectsContained: time info; pointer to central parameters & data object; structure of pointers to locations; structure of pointers to humans; ...

Methods: tick (passage of time, inform human objects to respond, inform central parameters & data object to respond); start ticking for some # days; ...

Constructor to Build Instance of Object: ...

Location

Fields/States&ObjectsContained: pointers to central parameters & data and clock; internally identifying # and category; structure of pointers to humans who are often in this location (for program form which is simple wrt location – e.g. a few categories of location related to day-of-week & time-of-day and several locations of each category and each location with certain humans associated; other simple program forms can also have location categories which can be visited more randomly by humans; could also have structure of pointers to humans currently in this location); ...

Methods: ...

Constructor to Build Instance of Object: ...

Human

Fields/States&ObjectsContained: pointers to central parameters & data and clock; internally identifying #; locations by category & # which often in / associated with (program form simple wrt location); fields related to infection status; whether interacting/isolating/etc.; ...

Methods: respond to tick / passage of time wrt state; respond to tick / passage of time wrt action / movement & interaction; methods related to interactions and infections/transmissions; ...

Constructor to Build Instance of Object: ...

C. Phase 2/2A program structure

Here summarized is the object-oriented program structure for the Phase 2 program SimAnalogSim, listing in summary form for each class of objects the fields (state variables & objects contained), methods/actions, and how instances are constructed:

Run SimAnalogSim

A main method that does the following: get input/values info from user of program (# days to run simulation(s), # SimAnalog humans at start of simulation, title/name to use for outputs of simulation(s), # SimAnalogSims / infection simulations of SimHumans based on simulation of SimAnalog humans, for each infection simulation whether to start an epidemic & how many infectious SimHumans at start & proportion of SimHumans in general transmission prevention mode) & based on this input also make sure there will be enough locations of each category; objects in simulation are made directly or indirectly – make central parameters and data, make clock (which makes locations & SimAnalog humans (which make SimHumans)); adjust initial conditions to start epidemics as specified by user; record the input & some starting info through the central parameters and data; tell clock to start ticking for the number of days specified by user; ...

Central Parameters and Data

Fields/State&ObjectsContained: pointer to instance of clock; info on # SimAnalog Humans (which is also equal to # Sim Humans for each SimAnalogSim), # SimAnalogSims (which is also equal to # SimHumans for each SimAnalog Human), title(s) for SimAnalog simulation & SimAnalogSim simulations, for each SimAnalogSim the proportion of SimHumans in general transmission prevention mode; parameter values for simulations (very simply chosen just for illustrating program structure, mostly partly realistic partly arbitrary constant

values/without distributions); cumulative & daily tallies of cases & cases by location for each SimAnalogSim; stuff to record longitudinal details for simulation of analog humans, longitudinal details for Sim Humans in each SimAnalogSim and data of cases and cases by location for each SimAnalogSim; ...

Methods: respond to tick of clock; ...

Constructor to Build Instance of Object: ...

Clock

Fields/State&ObjectsContained: time; pointer to the instance of central parameters and data; pointers to locations in simulation; pointers to SimAnalog Humans in simulation; ...

Methods: tick and tell objects (specifically self/clock, SimAnalog Humans, central parameters and data) in simulation to respond to tick / passage of time (note Sim Humans are not directly told by clock to respond but instead respond based on messages told them by SimAnalog Humans); start ticking for certain amount of time; ...

Constructor to Build Instance of Object: ...

Location

Fields/State&ObjectsContained: pointers to the clock instance & the instance of central parameters and data; identifying#; category of location (evening/night-time or morning/afternoon-time); pointers to SimAnalog Humans with a tendency to be in this location (depending on time of day); ...

Methods: ...

Constructor to Build Instance of Object: ...

Sim Analog Human

Fields/State&ObjectsContained: pointers to the clock instance & the instance of central parameters and data; identifying#; whether interacting (/allowing interactions); which home location & which activity location; pointers to the associated Sim Humans (1 for each SimAnalogSim); (note that in this simple simulation the current location is simply based on time of day);

Methods: how respond with respect to state when clock ticks (in the morning); how respond with respect to action (mainly interactions) when clock ticks to designate beginning of morning/afternoon time period or beginning of evening/night time period; methods related to interactions; ...

Constructor to Build Instance of Object: ...

Sim Human

Fields/State&ObjectsContained: Sim Analog Human that associated with; SimAnalogSim that associated with; (current location is implicitly same as associated SimAnalog Human); status with respect to infection; mode with respect to general transmission prevention practices; whether interacting (/allowing interactions); parameter related to probability that interaction with infectious person is infection transmitting; ...

Methods: how respond with respect to state when get message from associated SimAnalog human that clock has ticked indicating to respond with state (e.g., any applicable changes to infection status); methods related to interactions based on interactions of associated SimAnalog human and based on whether interacting and based stochastically on whether in

general transmission prevention mode, also interactions can possibly stochastically lead to infections; ...

Constructor to Build Instance of Object: ...

D. Phase 3/2B program structure, coordinate-based or signal/distance-based

Simulation of Epidemic Simulation Tool with Coordinate-Based or Signal/Distance-Based Proximity Detection.

Here summarized is the object-oriented program structure for the coordinate-based and signal/distance-based Phase 3 program SimAnalogSimProximityDetection, listing in summary form for each class of objects the fields (state variables & objects contained), methods/actions, and how instances are constructed. The main differences between the program for coordinate-based and for signal/distance-based is that the former also displays/records information and data spatially (i.e., mentions locations) and that for coordinate-based proximity detection the smart device interaction detection/inference involves communication of information from each smart device to central computer which can then share with each smart device the nearby information while for signal/distance-based proximity detection the smart device interaction detection/inference involves signals/information exchange directly between smart devices which are near each other.

Run SimAnalogSim ProximityDetection1(coordinate-based)or2(signal/distance-based)

Main Method: interpret user input; do some setup for simulating analog world; make objects for simulation (directly or indirectly); make sure objects have any of the user input necessary for epidemic simulation tool to setup epidemic simulations; tell clock to start ticking for the number of days specified by user; ...

Central Parameters & Data for Sim Analog

Fields/State&Objects Contained: pointer to clock; parameters for analog world; stuff for recording some info & data on analog world (including basic characteristics like # humans & # locations, data on where analog humans go over time); ...

Methods: (recording info & data occurs at various points in program); ...

Constructor to Build Instance of Object: ...

Clock for Sim Analog

Fields/State&Objects Contained: time info; pointer to central parameters & data for sim analog; pointers to locations in analog world; pointers to analog humans (& directly or indirectly to smart devices); pointer to central computer; ...

Methods: tick (passage of time, tell objects in analog world to respond to passage of time); start ticking for certain amount of time; ...

Constructor to Build Instance of Object: ...

Location for Sim Analog

Fields/State&Objects Contained: pointer to clock; pointer to central parameters and data for sim analog; category of location; index # of location (in simple simulated analog world locations are identified by category & index #); pointers to humans currently in location (for main activity & home locations this is assigned & depends on time-of-day & if

weekday/weekend; for short activity locations this is not assigned & randomly varies each weekend day); total number of humans currently in location; ...

Methods: ...

Constructor to Build Instance of Object: ...

Analog Human

Fields/State&Objects Contained: pointer to clock; pointer to central parameters and data for sim analog; identifying number (for simulation of analog world); pointer to smart device; index of assigned home location and index of assigned main activity location; current location; ...

Methods: responses to tick of clock (passage of time); method to decide whether to visit a short activity location and if so randomly choose which one; (implicitly goes to home and main activity locations depending on time-of-day and if weekday/weekend); methods to (implicitly interact and) have smart device detect/infer interactions; ...

Constructor to Build Instance of Object: ...

Smart Device

Fields/State&Objects Contained: pointer to clock; pointer to central parameters and data for smart device; pointer to analog human carrying it; (current location in simple sim is same as analog human, it can be detected by smart device for coordinate-based and it is implied for signal/distance-based); pointer to associated interpreted analog human; pointer to central computer; ...

Methods: respond to tick of clock (mostly pass on message to interpreted analog human to respond to passage of time); detect/infer interactions for interpreted analog human (implied that smart device gets info related to nearby interpreted analog humans and sets of sim humans by giving/getting information / communicating with central computer for coordinate-based and by exchanging signals/information with other smart devices nearby/in-same-location for signal/distance-based); ...

Constructor to Build Instance of Object: ...

Central Parameters & Data for Smart Device

Fields/State&Objects Contained: pointer to smart device; some basic information of analog sims (epidemic simulations); some parameter values for infection simulations; stuff for recording/displaying some info on interpreted analog human and sim humans (interactions over time and/or infections over time); ...

Methods: (recording info occurs at various points in program); ...

Constructor to Build Instance of Object: ...

Interpreted Analog Human

Fields/State&Objects Contained: pointer to smart device; some basic info on analog sims (epidemic simulations); pointers to associated sim humans (one for each epidemic simulation); (current location is same as that of smart device); ...

Methods: pass on message to sim humans to respond to passage of time; methods for interacting and when interact tell sim humans to possibly interact; ...

Constructor to Build Instance of Object: ...

Sim Human

Fields/State&Objects Contained: pointer to associated interpreted analog human; index of associated analog sim (epidemic simulation); (current location same as interpreted analog human); whether interacting (i.e. not isolating); whether in general transmission prevention mode (reduced level of interactions); status with respect to infection; ...

Methods: respond to passage of time with respect to updating infection status; methods for interacting and when interact possibly get/transmit infection; ...

Constructor to Build Instance of Object: ...

Central Computer

Fields/State&Objects Contained: pointer to clock; pointer to central parameters and data for central computer; ...

Methods: respond to tick of clock (mostly tell central parameters and data to reset daily simulated infection tallies); ...

Constructor to Build Instance of Object: ...

Central Parameters & Data for Central Computer

Fields/State&Objects Contained: pointer to central computer; some basic information on analog world; some basic information on analog sims (epidemic simulations); stuff for recording info and data on analog sims (epidemic simulations); ...

Methods: (recording info & data occurs at various points in program); ...

Constructor to Build Instance of Object: ...

E. Phase 4/3 program structure, sample demonstration, place-based and coordinate based

The sample simple demo consists of several processes: a process to generate a synthetic map and synthetic location vs. time information for the implementation of each smart device's location detection; a process for a central computer / server; a process for each smart device; and a process to start the latter processes. The classes of objects which make up these processes are summarized below. Note that this code uses timers/threads/processes and the socket abstraction to communicate between processes in a way which does not fully avoid slight timing differences nor communication misses but instead keeps continual time-step-resolution testing logs for the server (central computer process) and each client (smart device process) throughout each full run in order to show for which part of the run the demonstration worked well enough and for which part of the run, if any, the demonstration's sample results are not worth looking at; it is probably preferable to look at sample results from runs which worked well throughout, but it is sometimes also still useful to look at sample results from runs which worked well from beginning until some point in the middle and then just ignore the rest until the end – it depends on what the testing logs record. The communication misses are allowed for the simple demo because it is good enough for demonstration, because the demo has a fast-forward time-scaling, and because the demo runs multiple processes (server and each smart device process) from one computer; also, as discussed in the main text, there is the flexibility to allow the epidemic simulation tool to be more approximation and simulation than inference.

For process for setting up other processes:

Simple Demo Communicating Processes Epidemic Simulation

Main Method: process user-provided arguments/input from prompt in order to pass these on as arguments to other processes; start process to generate synthetic map and synthetic location vs. time info for each smart device to detect; start process of central computer / server; start process of each smart device;

For process of generating synthetic map & synthetic location vs. time information:

Generation Synthetic Info:

Main Method: process arguments; build objects directly (central params & data, clock) and indirectly (clock builds synthetic locations and synthetic analog humans); start synthetic clock ticking for the # days for which want to generate synthetic location vs time info for each synthetic analog human; ...

Synthetic Info Central Parameters & Data:

Fields: parameters for generating synthetic info & basic info on synthetic info generated;

...

Constructor: ...

Methods: ...

Synthetic Clock:

Fields: pointers to objects in this process; time info; ...

Constructor: generate simple synthetic map with areas indexed according to adjacency and within each area places of different categories; build synthetic analog humans with location preferences for some of the place categories; ...

Methods: tick to indicate passage of time to objects in this process; ...

Synthetic Location:

Fields: indices identifying this location & its type; implicit or pointers to synthetic analog humans currently in location or with preference for this location; ...

Constructor: ...

Methods: ...

Synthetic Analog Human:

Fields: if any location preferences for some place categories; current location; ...

Constructor: ...

Methods: respond to tick / passage of time by staying or moving location according to time & day &/or preferences &/or randomness, including time to move between places according to how far they are from each other; ...

For process of central computer / server:

Central Computer Process:

Main Method: process arguments; build central parameters & data object; set up server listening socket; arrange so that each new connection request from a client sets up a connected

socket for a new associated server thread and start that thread going; in simple demo each smart device uses one connection to server throughout; ...

Central Computer Central Parameters & Data:

Fields: basic info on map & epidemic simulations; frequent-turnover data structures for temporarily gathering sim-human characteristics by location for a couple of timepoints at a time; stuff for displaying simulated new infections data collected; ...

Constructor: ...

Methods: methods which do the bulk of the calculations for processing communications relayed by server thread & possibly responding to communications by relaying back to server thread; method for temporarily gathering info on sim-human characteristics at a location for a timepoint; method for returning gathered info on sim-human characteristics at a location for a recent timepoint; methods for gathering simulated new infection data (and also for gathering initial infectious #'s into cumulative tally) and periodically (daily) displaying it; ...

Central Computer Server Thread:

Fields: server end of a connected socket; pointer to central parameters & data;

Constructor: ...

Methods: has a method which runs when this thread is told to start – this method receives communications from a client and then processes the communication and possibly responds to the client, using some of the methods in the central parameters and data object; ...

For process of each smart device:

Smart Device Process:

Main Method: process arguments; build directly or indirectly objects for this process; build a client end socket to connect to server / central computer; start a periodic set of tasks (object periodic task); ...

Smart Device Central Parameters & Data:

Fields: basic info on map & epidemic simulations; parameters for sim-human infection status progression; parameters for inference/simulation of interaction transmissions; stuff for locally (on smart device) displaying some info on sim-humans (if person carrying smart device is interested); location during current timestep & location during previous timestep; additionally for coordinate-based, random temporary non-unique index; also additionally for coordinate-based, frequent-turnover data structure for tallying consecutive # times another sim human with a given (for each possible) random temp non-unique index coincides in same gridbox; ...

Constructor: ...

Methods: ...

Smart Device Central Methods:

Fields: stuff for implementation of location vs. time detection (simple demo uses synthetic information for this); pointer to associated interpreted analog human; ...

Constructor: ...

Methods: method for detecting location in time; ...

Periodic Task:

Fields: pointers to smart device central parameters & data and central methods; pointers to client end communication inputs & outputs from connection with server; ...

Constructor: ...

Methods: a method which runs when periodic task object is started – a set of tasks to go through periodically, including retrieving from server characteristics of sim-humans at same location/place around previous timestep and using this to infer/simulate if possible new interaction transmissions in which case send new infection data to server, for current timestep updating the infectious status of associated sim-humans, for current timestep detecting location in time and sending that information along with sim-human characteristics to server and for coordinate-based also along with a stochastically intermittently randomly (re-)selected temp non-unique index; the periodic set of tasks use some of the methods & fields from central methods and central parameters & data; ...

Interpreted Analog Human:

Fields: pointer to set of associated sim-humans – one for each epidemic simulation; current location is implicitly same as smart device; ...

Constructor: ...

Methods: ...

Sim Human:

Fields: index of associated epidemic simulation; pointer to associated interpreted analog human; current location is implicitly same as smart device unless not interacting/isolating in which case current location is anyways not used in calculations; infection status; whether interacting or not/isolating; whether in general transmission prevention mode; ...

Constructor: ...

Methods: method for inferring/simulating interaction transmission; method for updating infection status; ...

F. Program code for phase 1, phase 2/2A, phase 3/2B, and phase 4/3

Files of the program code for Phase 1, Phase 2[2A], Phase 3[2B] (coordinate-based and signal/distance-based), and Phase 4[3] (place-based and coordinate-based) are available both as java files organized within folders into one zip file (Online Resource 1) and as pdf files which contain the text content of the java code files together for Phases 1 and 2 (Online Resource 2), Phase 3 coordinate-based and signal/distance-based (Online Resource 3), and Phase 4 place-based and coordinate-based (Online Resource 4). (Also text content for a very slight modification to code for coordinate-based sample simple demo of epidemic simulation tool is found in Online Resource 5.)

G. Additional small notes mentioned in the main body of text.

Rather than footnotes or parenthetical clauses, listed below are small additional notes indexed by lowercase letter which are mentioned in the text. Some of these notes describe, for example, more complex or specific aspects, limitations, variations, or extensions to consider for computational structures.

(a) Note that since likely not all humans/devices would give access to spatial information, then work-arounds would be used such as various modeling calculations or such as having some of

the humans in the simulation be fully digital/simulated rather than having all humans being analog-based spatially and further even the analog humans/devices could sometimes be replaced by fully digital/simulated humans so that no human/device requires to constantly give spatial information – e.g., more specifically an algorithm could be used to generate synthetic humans whose spatial movements are similar to some actual device spatial information in terms of categories and relative distances of locations visited in time but different in terms of geographic areas of locations or specific locations.

(b) One other main note in relation to information access is whether age-category information would be useful to have. If the epidemic simulation tool is for more abstract purposes then it does not matter, but if the intent is to simulate less abstractly then this should be considered. Interaction patterns are sometimes age-dependent and so epidemiological models sometimes include age categories; however, with this tool the interactions are generated through information inferred from analog humans / smart devices and already implicitly incorporate any age-dependence. Now, if the purpose is to just simulate cases but not necessarily severity of cases, which may or may not be age-dependent, then the tool might still work without asking for age-category information; however, if the purpose is to simulate an infection which has age-dependent severity then it is likely that another purpose is to simulate age-dependent control measures/programs – for this, even if one is just interested in cases, it would still be useful to ask for age-category information, whereas just simulating the age-category variable in an independent way would not work because the interaction patterns are sometimes age-dependent. Further, if an infection has age-dependent susceptibility or age-dependent transmissibility, even after separating out the age-dependent interaction component, then for the tool to be useful for simulating cases it may ask for age-category information. The tool asking for age-category may be similar to a smart device app asking for age-category in order to perform required calculations, which would not be very unusual because many online applications for example ask for even more / exact age. However, if the tool is being used for an infection which has co-morbidities, it would be unusual to request co-morbidity information and so this variable could be simulated if it is of interest and depending on the purposes.

(c) As another note, the simple demo of the epidemic simulation tool comprised processes for 50 smart devices and 1 server. With more smart devices, it is possible to also consider structures with more servers. There are various reasons why one may consider multiple servers, but this note just discusses a couple of simple approximate uses of multiple servers. (Similar to the added method descriptions of proximity detection and anonymity, these descriptions are rough and extend from the considerations for the initial phase sample, simple and abstract computational structures; the points and aspects described may be useful for considerations in later phases; later phases would also add rigorous specifics for implementations on mobile phones and servers of computational structures developed by researchers from multiple fields/disciplines.) For the epidemic simulation tool server role of collecting spatial simulated infection data, if there are many devices communicating spatial simulated infection data around some time then the structure could have different devices communicate their spatial simulated infection data to different servers depending on the spatial location of the data or based on some random assignment to split different device communications to different servers; then that data from the different servers could be communicated to another server which combines all the simulated infection data for that time in the form that can be displayed. For the temporary/small time interval of spatial sim humans infectious statuses information, the demo built so far is coordinate/space/location-based and communicates this information from each smart device to a

server and then the server communicates some spatially collected amount to each smart device; with a large map and multiple devices, different servers could be assigned to different portions of the map, and a device would communicate/give/receive this temporary information with the server assigned to the portion of the map in which the device is currently located or the portion of the map for which the device is exchanging information – this is an approximation in part because for some algorithms it may ignore when a device goes between portions. For variations which also calculate possible interactions between devices moving together, the portions could be made large enough to detect this – e.g. if counting the number of consecutive times two simhumans coincide, while still being approximate for when devices move between portions. If a demo is built for signal/distance-based proximity detection with communications being direct between smart devices for the temporary small time interval (spatial because signal/distance-based) sim humans infectious status info, then servers are not considered for these communications, at least not at the rough level of simulations/demos/discussions here.

(d) Another short-term goal computational structure to build in a next phase might be a simple demo as done already here but programmed for a small number of actual mobile phones (rather than just separate computer processes abstractly representing separate mobile phones, as has been done already here). A further phase would consider larger scales with respect to numbers of mobile phones, relative speed and space for computations in later phases, time duration of simulations, geographical resolution and range, and time resolution of proximity detection. Such phases would require more detailed choices (or choices based on later phases rather than initial illustrative phases) and the use of additional concepts from the multiple related disciplines.

(e) There are also two categories of epidemiology calculations which might be done in a way which is computationally similar to the epidemic simulation tool; while the epidemic simulation tool incorporates in real-time proximity inferences from spatial information into an epidemic model for epidemic simulations, another tool might incorporate in real-time spatial information of mobile phones to generate somewhat similar synthetic longitudinal spatial data which can then be used by epidemiology researchers, and yet another tool might incorporate in real-time spatial information of mobile phones to calculate descriptive quantitative and qualitative parameters about spatiotemporal interactions which might be useful to epidemiology researchers. As for the epidemic simulation tool, the details of what would be useful and how to implement the calculations would need to be designed by researchers of multiple disciplines, and there are already some complementary (or perhaps similar, even moreso than for the epidemic simulation tool) methods already in the research literature.

(f) It would also be worthwhile at some point to incorporate or consider more specifically human-environment interactions rather than just human-human interactions.

(g) As mentioned in the introduction and methods, it may be useful to consider variations of the epidemic simulation tool which allow not only information access on mobile devices but also temporary storage of information on mobile devices. For location-based interaction inference (with location detection such as GPS), if mobile devices temporarily store their location in time information, then epidemic simulations using recent past information could be run in a fast-forwarded time scale using a similar distribution of calculations and communications among and between devices and servers; For distance/signal-based interaction inference (with detection such as bluetooth communication between mobile devices), if mobile devices additionally have temporary identifiers and keep track of their identifiers over time and have temporary storage of the nearby identifiers they encounter over time, then a variation may be built with distributed

calculations and communications between mobile devices and servers which allow epidemic simulations using recent past information to be run in a fast-forwarded time scale.

(h) Note that this research has also been presented in shorter form as a Poster in the 2021 ASTMH Annual Meeting (conference by the American Society of Tropical Medicine & Hygiene) [27].

(i) Note that stochasticity in the epidemic simulations arises from an epidemic simulation model which is partly deterministic and partly stochastic, as well as stochasticity in the partly deterministic partly stochastic process of generating the spatiotemporal synthetic information corresponding to a set of epidemic simulations; also, there is some small level of additional stochasticity because the code for the simple demo allows computations to proceed approximately despite a small level of random errors in occasional communication misses or slightly varying possible orders of communications – related to each timestep – between the server and each mobile device, with completion of computations and communications per timestep approximately roughly synchronized among the mobile devices. The code generates logs – for the server and each mobile device – with each run of generated synthetic spatiotemporal information and a set of corresponding epidemic simulations; the logs approximately show whether the communications between mobile devices and server and related computations proceeded well enough to produce illustrative output – with close enough order and with few enough communication misses and with enough synchrony for timesteps or for daily tally computations.