Using agent-based modeling to understand HIV transmission, care, and prevention

Edinah Mudimu, Ph.D.
Senior Lecturer
Decision Sciences
University of South Africa
Outline

• **Introduction** – why mathematical modelling in epidemics

• **Overview of EMOD**

• **Overview of STI-HIV model in EMOD**

• **Results:**
  – Role of voluntary male medical circumcision (VMMC) in reducing HIV incidence and ensuring a sustainable response
  – PrEP

• **Conclusions**
Introduction – why mathematical modelling in epidemics

Understand health care system
Number on treatment by demographic suppression rates, fate of those LTFU

Impact on survival and transmission
Cohort studies of survival, suppression
Transmission studies controlling for suppression

Measured incidence patterns
Challenges of new assays
Biases from sampling, consent

Measured mortality
Challenges of assigning cause of death as conditions change
Typical mathematical modeling process

http://www.vcyang.com/model_flowchart/
Mathematical models are further classified into compartmental or agent-based models.
EMOD: Institute for Disease Modeling (IDM)

- Founded in 2007 to support Gates Foundation initiative to eradicate malaria
- Not-for-profit research group hosted within a private company, Intellectual Ventures
- Grew to ~100-person institute dedicated to quantitative analysis for global disease control and eradication
  - 2/3 research and policy “think tank”
  - 1/3 software “startup”
- Create professionally built and tested, re-usable tools
- Give them away for free: www.idmod.org and www.github.com/InstituteForDiseaseModeling
Overview of EMOD

Transmission Modes with Disease-Specific Features

Bershteyn et al., Pathogens and Disease, 2018.
https://europepmc.org/abstract/med/29986020
Overview of EMOD

Generic SEIRS

Environmental
- Polio
- Typhoid

Vector
- Dengue
- Malaria

STI
- HIV

Airborne
- TB
- TB/HIV

Custom
- > 600 regression tests
- > 140 scientific feature tests
  - “black box” testing
  - E.g. Kolmogorov-Smirnov test of a statistical distribution after random perturbation
- > 40 component tests
  - a.k.a. unit tests, instantiates a subset of the code base in isolation
  - “white box” testing
  - examine software components that are not user-facing, such as unique identifiers for individuals
- Extensive online documentation
  - Tutorials [www.idmod.org](http://www.idmod.org)
  - Parameter definitions, units, and ranges

---

**Shared across EMOD**

[www.github.com/InstituteForDiseaseModeling](http://www.github.com/InstituteForDiseaseModeling)

- **Generic**
- **Environmental**
- **Envir. + Polio**
- **Envir. + Typhoid**
- **Vector**
- **Vector + Dengue**
- **Vector + Malaria**
- **STI**
- **STI + HIV**
- **Airborne**
- **Airborne + TB**
- **Airborne + TB + HIV Co-Infection**
- **Custom**

**Total Lines of Code**

- **Blue** = common framework
Connecting blocks using triggers

Inside the model
Broadcasts an event
*e.g.*, pregnancy, new infection, AIDS symptoms

Listens for the event

Broadcasts an event
*e.g.*, MyCustomEvent

Listens for the event

Build up complex health care systems
Building Blocks of the Health Care System

{ When
{ Who
{ Why
{ What
Tx, Dx, Prevention, Delay, Filter, f(t)

Image credit:“ Brand new bricks ” by fdecomite, CC BY 2.0.
"Event_Name": "HIV diagnosis in 6-week-old children",
"class": "CampaignEventByYear",
"Start_Year": 2004,
"Nodeset_Config": {
  "class": "NodeSetAll"
},
"Event_Coordinator_Config": {
  "class": "StandardInterventionDistributionEventCoordinator",
  "Intervention_Config": {
    "class": "NodeLevelHealthTriggeredIV",
    "Property_Restrictions_Within_Node": {
      "Accessibility": "Yes"
    }
  },
  "Trigger.Condition_List": [
    "SixWeeksOld"
  ],
  "Actual_IndividualIntervention_Config": {
    "class": "HIVPiecewiseByYearAndSexDiagnostic",
    "Days_To_Diagnosis": 0,
    "Event.Or_Config": "Event",
    "Female.Multiplier": 1,
    "Interpolation_Order": 1,
    "Time_Value_Map": {
      "Values": [0, 0.03, 0.1, 0.2, 0.3365]
    },
    "Disqualifying_Properties": {
      "CascadeState:LostForever",
      "CascadeState:OnART",
      "CascadeState:LinkingToART",
      "CascadeState:OnPreART",
      "CascadeState:LinkingToPreART",
      "CascadeState:ARTStaging"
    },
    "Positive_Diagnosis_Event": "ARTStagingDiagnosticTest",
    "New_Property_Value": "CascadeState:TestingOnChild6w"
  }
}
Example of model calibration: SA national
Conclusions

- Individual-based modeling can be used to evaluate interventions like ART, VMMC, and PrEP in the context of setting-specific transmission.
- New tools and strategies will be needed to dramatically reduce HIV incidence and burden for long-term epidemic control, EMOD can be used to test the new tools and strategies.
- EMOD is a resource to the community to test hypotheses, understand broader implications of new evidence, and evaluate intervention strategies.
Acknowledgments

• Kathryn Pebbles Institute for Disease Modelling
• Monisha Sharma from the University of Washington
• John Stover and Eline Korenromp from Avenir Health
• Leigh Johnson from University of Cape Town
• Supriya Sakar Emroy University
Thank you to wonderful colleagues at the Institute for Disease Modeling

Dan Klein, PhD
Bradley Wagner, PhD
Anna Bershteyn, PhD
Karyn Sutton, PhD
Stewart Chang, PhD
Adam Akullian, PhD
Dan Bridenbecker, MS
Chris Lorton, MS
Clark Kirkman, MS
Thank you… and happy to take questions