10 Uncomfortable Truths About Dynamic Modeling for Public Health

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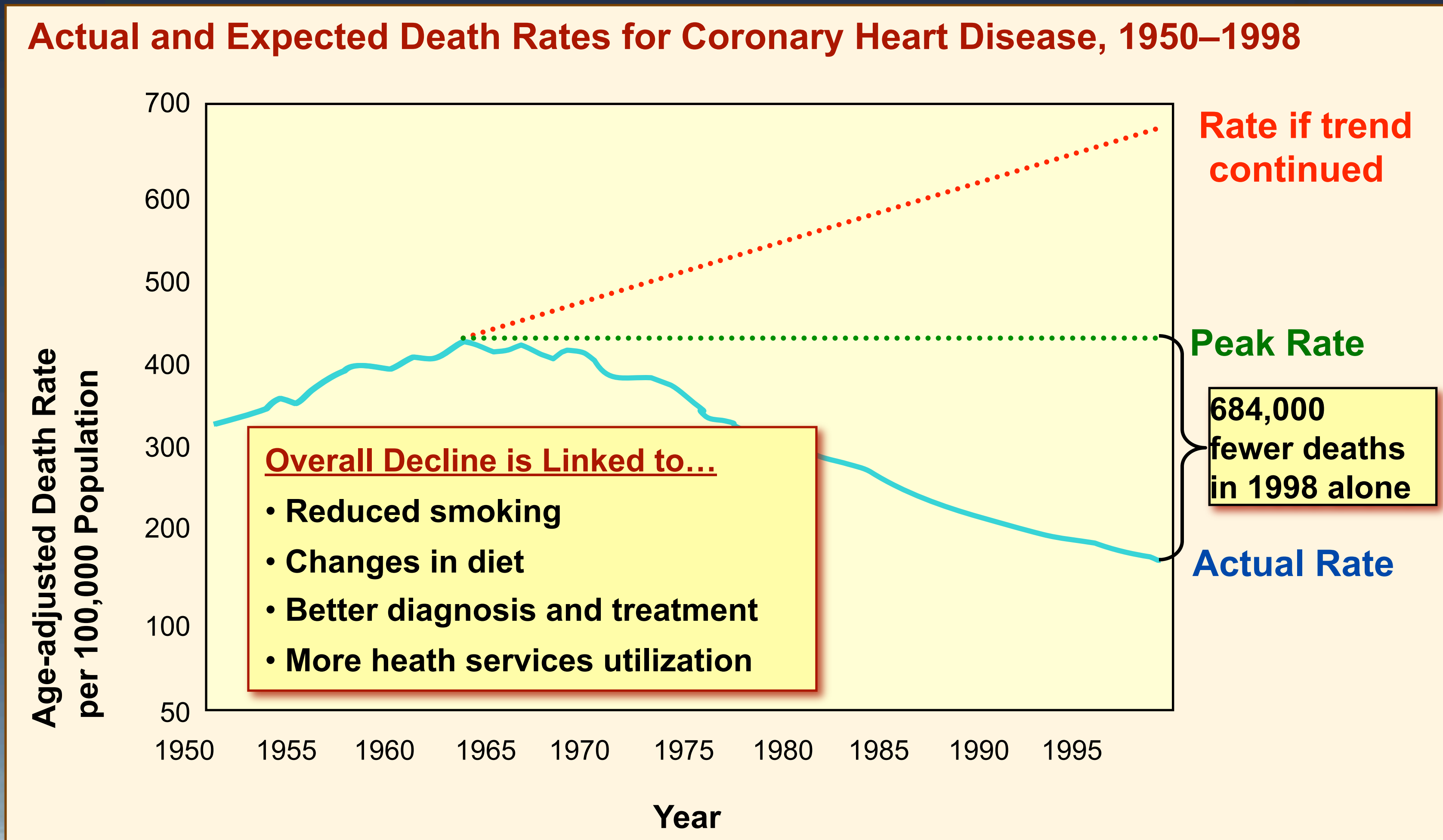
Public Health as "Redirecting the Course of Change"

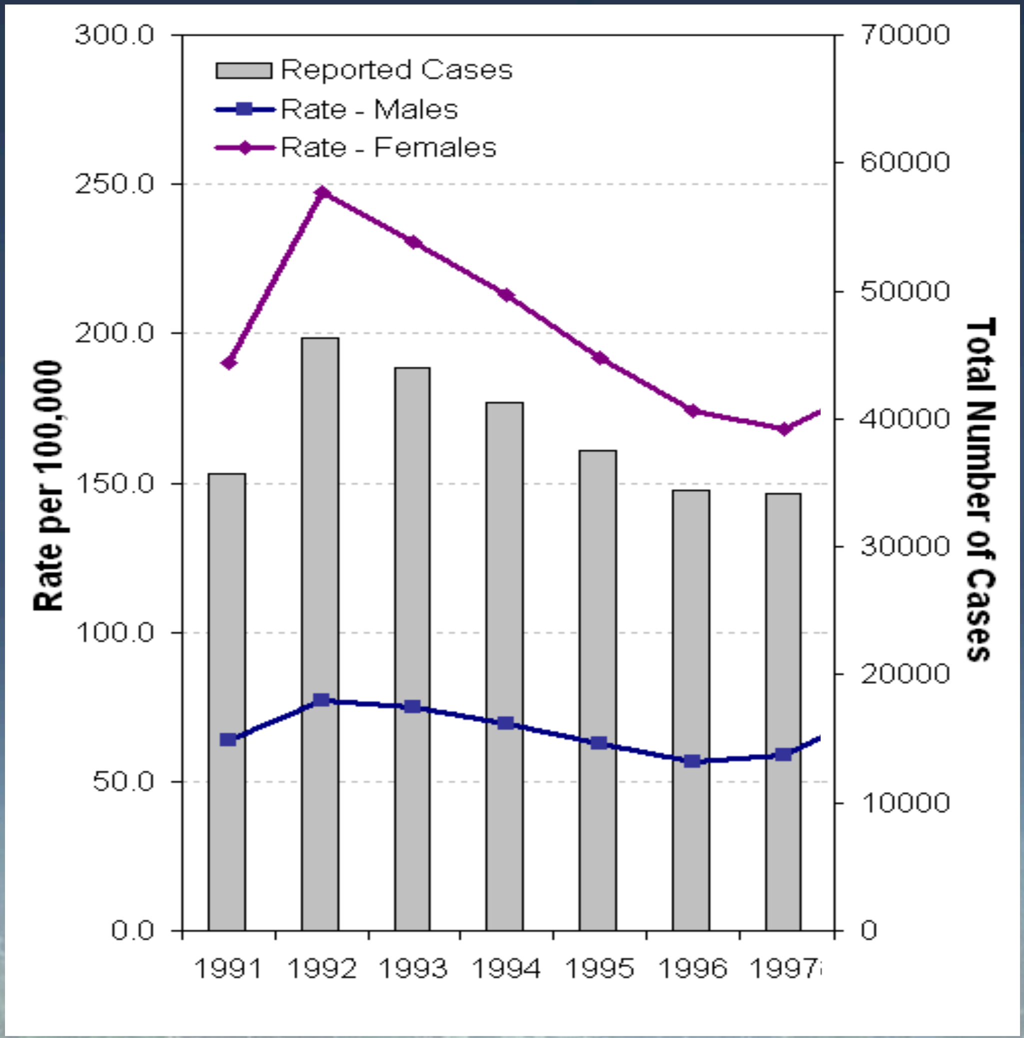


Adapted from Homer, Millstein, Osgood 2007

Marks JS. The burden of chronic disease and the future of public health. CDC Information Sharing Meeting. Atlanta, GA: National Center for Chronic Disease Prevention and Health Promotion; 2003.

Centers for Disease Control and Prevention. Achievements in public health, 1900-1999: decline in deaths from heart disease and stroke -- United States, 1900-1999. MMWR 1999;48(30):649-656. Available at <http://www.cdc.gov/mmwr/preview/mmwrhtml/mm4830a1.htm>

A Less Successful Example: Canadian Chlamydia Rates 1991-1997



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- Data for 2005 and 2006 are preliminary and are anticipated to change
- Source: Surveillance and Epidemiology Unit, Community Acquired Infections Division, PHAC

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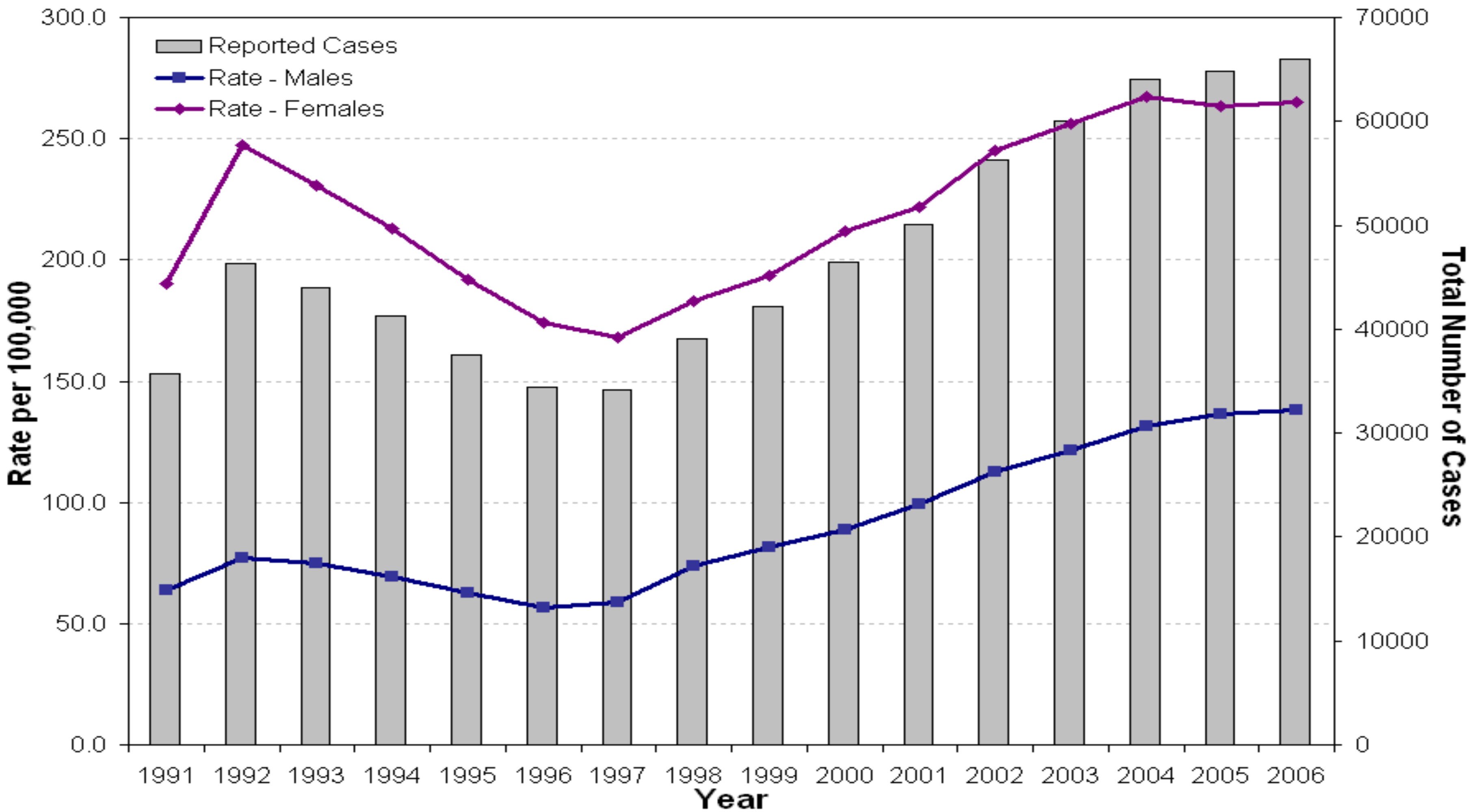

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Complexities

- Delays
  - Presentation of symptoms/Contact tracing/ Identification of asymptomatic
- Interactions (e.g. STIs & HIV, HCV&HIV, strains, Chronic & Infectious illness)
- Feedbacks
  - Intergenerational/social network mediated
  - Immune system
  - With healthcare system
  - Behavior change after knowledge of health status
  - Risk perceptions
- Nonlinear: Risk, cost, intervention synergies
- Heterogeneity in progression, behaviour

Complexities Matter for Intervention Selection

- **Blowback, multiplier effects**
- **Presence of "tipping points"**
- **Tradeoffs**
  - **Prevention vs. screening vs. contact tracing & treatment**
  - **Upstream vs. downstream interventions**
- **Evaluation of focused intervention**
- **Evaluation of intervention portfolios**

Dynamic Models: Uses

- **Make explicit mental models of causality, for discussion and collective refinement**
- **Assist in management of complex situations**
  - **Help make sense of trends**
  - **Serve as "What if" tool for identifying desirable policies**
    - Cost-effective/High-leverage/Robust
  - **Prioritizing research/data collection & identifying inconsistencies**
  - **Understanding commonalities between contexts**
- **Communication (e.g. "learning labs")**

Grim Truth

- Models offer tremendous potential
- We have a long way to go to realizing that potential
- Recognizing this is important
  - Many challenges are poorly articulated
  - We must manage expectations: Achieving the full benefits of models will take some time
  - Characteristic challenges can help muster support for overcoming them

10 Uncomfortable Truths

- ✷ **Many models too narrow to yield reliable guidance**
- **Intervention behavioural feedbacks are neglected**
- ✷ **Major barriers in all modeling approaches**
- ✷ **Many model specifications are needlessly opaque**
- ✷ **Data is mismatched&inadequate=>time&guessing**
- ✷ **Modeling processes are too entropic**
- **Modeling processes are too ad hoc**
- **Model secrecy impedes learning & potential**
- ✷ **Training rate falls far short of demand**
- ✷ **Tribal impulses shortchange health impacts**

✷: Areas addressed by our work

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A Dearth of Broad Models

- Despite recognized importance of behavioural factors, narrow models overwhelmingly more prominent
- Urgency, ease of understanding, collaborative network, exposure to critiques pushes towards narrow & deep
- The attraction of models focuses on use in intervention analysis & forecasting => Underplays use for learning

Key Effects Frequently Ignored

- Intergenerational factors (e.g. genetics, epigenetics)
- Social network effects
- (Localized) perception
- Impact of human/financial resource limitations
- Policy & industry responses
- Interactions with other conditions & risk factors
- Effects of changed incentives on decision making

Steps Forward?

- Greater support for “basic research”
  - Learning-oriented models
  - More conferences like this one!
- Broader teams
- Speaking truth to those in power

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Endogenous Intervention Impacts on Behaviour: Current Practice

- **Behaviour is exogenous to model**
- **Models link behavior to distal impacts**
- **Modelers impose assumptions of how interventions affect behaviour**
- **Models offer value in understanding emergent, distal implications of behaviour change**
- **We gain little insight into the counter -intuitive behavioral impacts of intervention**

Example Behavioral Feedbacks Underlying Much Policy Resistance

- Cutting cigarette tar levels reduces cessation
- Cutting cigarette nicotine levels leads to compensatory smoking
- ARVs prolong lives of HIV carriers, but lower risk perception
- Availability of reduced-fat/calorie varieties undercuts changes to eating habits
- Antilock brakes lead to more risky driving

Endogenous Intervention Impacts on Behaviour: Vision

- Modelers characterize intervention impacts on environment (e.g. prices, tax burden, $ incentives, laws)
- Capture indiv preferences&mental models, learning
- Model endogenously compute individual, localized behavioural responses (cf discrete choice theory, psych. models)
- Models provide insight into both
  - Distal implications of interventions
  - Behavioral impacts of intervention (individual&collective)

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Contrasting Benefits

Aggregate Models

- Easier
  - Construction
  - Calibration/Validation
  - Parameterization
  - Analysis & Understanding
- Performance
  - Lower baseline cost
  - Population size invariance
- Less pronounced stochastics
  - Less frequent need for Monte Carlo ensembles
- Quicker construction, runtime ⇒More time for understanding,refinement

Individual-Based Models

- Fidelity to some dynamics
- Support for highly targeted policy planning
- Clearer & more scalable heterogeneity represent.
- Examining finer-grained consequences
  - e.g. transfer effects w/i pop.
  - Network spread
- Simpler description of some causal mechanisms

Individual vs. Aggregate Models: Necessary Tradeoffs

	Transition Generality	Network Representation	Transparency scaling with Heterogeneity	Calibration	Performance Issues				Capturing Learning/ Adapation
					Basal	Scaling with Population	Scaling with Heterogeneity	Need for Stochastics/Monte Carlo	
Individual Models	++	++	++				++		++
Aggregate Models		+		++	++	++		+	

- Both individual-level and aggregate modeling have *inherent* and non-trivial *tradeoffs*
- Both approaches likely to retain strong appeal in systems modeling

Current Packages: Less Representative of Fundamental Tradeoffs

- **Existing modeling options are unrefined**
- **The tradeoffs associated with the happenstance of package features can exceed those associated with modeling methodologies**

Multi-Framework Modeling

- **We have found the use of multiple frameworks most effective**
  - **Co-evolving multiple models for**
    - Cross-validation
    - Asking different sorts of questions
  - **Within a single model (cf Multi-scale modelling)**
- **Critical that dynamic models leverage with non-dynamic modeling tools**
  - **Decision trees**
  - **Game theory**
  - **Biostatistical analyses**

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Specification Mechanisms Are Gratuitously Opaque

- **Model understanding is obscured by welter of implementation trivia**
- **Steep learning curves**
- **Inaccessible for many modelers**
- **Errors**
- **Difficult to**
  - **Understand structure**
  - **Communicate & critique**
  - **Reproduce**

Steps Forward?

- Declarative mechanisms: Describing the “what” with minimal “how”
- Domain specific languages (cf Frabjous)
- Advantages
  - Lower risk of errors
  - Higher productivity
  - Improved communication (esp. interdisciplinary)
  - Easier reproduction
  - Greater credibility

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The "Data Gap": Moving Beyond Data Scavenging

- **The data at our disposal prevents models from investigating many questions**
- **Broad categories of domain have little data available (e.g. social networks for health contexts)**
- **Where data is available, it is often not posed in a manner suitable for modeling**
- *Opportunity cost*: **The time spent massaging & casting around for data is time taken away from other key tasks & insights**

Moving Upstream

- **Modelers should partner with those responsible for data collection**
  - **Administrative data: Repositories & algorithms**
  - **Health surveillance instruments**
  - **Clinical data collection**
  - **Ambulatory data**

Data: Big Opportunities

- Public health observatories & data repositories
  - Algorithm & surrogate development
  - Cross-linking
- Broad-based mobile-computing electronic ambulatory assessment
  - Health trajectories
  - Social context
- User-contributed metadata

Public Health Observatories

- Cross-linking & annotating multi-level data
  - Multiple cross-sectional & longitudinal survey instruments (health status, risk factors)
  - Administrative data (e.g. diagnostic codes, pharmaceutical & healthcare utilization, vital statistics, cost & resource use, education, justice, housing, …)
- Critical components
  - Confidentiality
  - Federated data access at different levels of resolution & authority
  - Rich & consistent metadata
  - Case ascertainment algorithms
  - Data cleaning
- Strongly empowers
  - Systems modeling efforts
  - Derivation of surrogate measures for conditions
  - Context-rich cross-sectional & longitudinal analysis
- Priorities
  - Incorporation of
    - Contextual information
      - (De-identified) & cross-linked social /family network data
      - Determinants of health (e.g. Socio -economic status)
      - Intervention history
    - Transparent systems models
    - Data cleaning & analysis algorithms
    - Ecological momentary assess. data
    - Community-contributed metadata
  - Rewarding contributions
  - Operational support
  - Voluntary privacy waivers?

Opportunities for Improving Data

- **Incorporating members of shared social networks**
  - **Parents/Siblings/Peers**
  - **Longitudinal resolution key: recognize whether born before or after parental disease or stressors**
  - **Partial surrogate: Questions regarding family, peers**
- **Identification of condition/risk factor surrogates in administrative data**
- **Informing survey question prioritization w/ dynamic models**
- **Adding history-related questions on**
  - **Time since *[Behavior change]***
  - **How often did you *[Behavior]***

Opportunities for Improving Data (2)

- **Cross-linking data sets**
  - **Risk factors & attitudes**
  - **Self-reported conditions**
  - **Social networks**
  - **EMA data (self-report & sensor-based)**
  - **Administrative data (e.g. health service utilization, drugs, vital statistics, hospitalizations, death repeats)**
- **Maintaining overlap, consistency in variables**
  - **Synchrony of multiple studies? (for common baseline)**

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Process Complexity: A Barrier to Quality System Dynamics Modeling

- **Medium+ scale modeling projects generate large # & diversity & versions of related artefacts**
- **Careful coordination of these artefacts is important for ensuring quality insights**
- **Efficient coordination is important for productivity**
- **Existing tools offer limited support for such coordination**
- **Difficulties limit what can be accomplished**

Why the Gaps Matter

- Process transparency
- Risk of modeling errors
- Stakeholder confidence
- Speed of learning
- Modeling efficiency
- Practical limits on project scope

Partial Solution: Software Support (SILVER)

- Model version control
  - Rollback
  - Comparison with earlier versions
- Ability to collaborate on shared artifacts
  - Communication of artifacts across machine/institutional boundaries
- Reification of structured scenario collections
- Maintenance of explicit links & referential integrity b/t
  - Versions & scenarios
  - Concept. linked scenarios
  - Metadata & data
    - Motivation for creating scenario collection & scenario outputs
    - Artifacts & docs on intentions for producing them
    - Definition of scenario & output
    - Output & analysis documents
- Distributed evaluation of large scenario sets

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An Ad-Hoc Modeling Process

- **Ad-hoc processes for interacting**
  - **With stakeholders**
  - **Gaining understanding of needed model structure**
  - **Gaining confidence in models produced**
- **Welter of artifacts produced**
- **Integration between teams**

Additional Elements

- Conscious use of methodologies
- Peer reviews
- Testing regimes
- Pair modeling
- Adaptive & Incremental delivery
- Formal requirements processes
- Change control processes
- Risk-driven development
- Continuous integration
- Modularization

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Poor Model Sharing & Disclosure

- **Few models are currently disclosed with enough detail to allow for reproduction**
  - **Incentives do not promote sharing**
- **The lack of disclosure lowers ability to critique & refine models**

Steps Forward?

- Funding, publication incentives could foster a cultural shift
- Synergy: Incorporating annotated models w/i public health repositories

Example: Bioinformatics Community

- **Enormously rich annotated cross-linked databases**
  - **Federal support (e.g. PDB, SwissProt, EBI, GENBANK, …)**
  - **Cross-linking key to use & realized value**
- **Cultural norms & incentives value shared contributions**
  - **Reputation accrues through sharing**
  - **Sharing encouraged/required through**
    - Funding guidelines
    - Publication policy
    - Society guidelines & consensus statements
  - **Shared data fairly standard**
  - **Shared code encouraged**
- **Programmatic data access & services (via web services)**

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Modeler Training: A Haphazard Process

- Tribalism & methodological specialization
- Learning on the street
- Fosters methodological specialization
  - Frequently only learn one dynamic modeling technique
  - Incomplete knowledge of techniques in cognate areas

Steps Forward?

- **Need training avenues for those not exposed to dynamic modeling mathematics & software through UG**
- **Specialized training for health modeling**
- **Broad knowledge for integration with other formalisms**
- **Required exposure of modelers to basic courses in cognate fields**
  - **Biostatistics**
  - **Epi**
  - **Behavioural sciences**

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Tribal impulses shortchange health impacts

- Reduce collaboration opportunities
- Fail to build up cross-camp institutional knowledge
- Needlessly confuse stakeholders
- Lead to mis-application of approaches
- Lock-in: Limit student opportunities for broader training

Steps Forward?

- Building a sense of domain- (rather than methodology-)based identity
  - "Dynamic modeling for health" journals, conferences, etc.
  - Requiring student work with multiple methodologies
- Cross-methodology modeling contract requirements

Conclusions: Danger & Opportunity

- **Models currently offer much value, but…**
- **We are far from realizing the full potential of such models**
- **By articulating the problems, we have a good chance of marshalling the resources to overcome them**

Acknowledgements

- **Students**
- **Collaborators**
- **Support from funding agency**
  - **NSERC**
  - **Saskatchewan Health Research Foundation**
  - **CIHR**
  - **Lupina Foundation**

Agenda

- ✓ Motivations for mathematical modeling
- ✓ Mathematical models: Structure & process
- ✓ Heterogeneities & individual-based modeling
- ✓ Mathematical theory of infection
- Conclusions

Conclusions

- Interventions affecting infectious diseases are interventions in a complex system
- This complexity impacts intervention choice
  - Identifying “best” intervention is difficult!
- Mathematical modeling can help assist in the judicious choice of interventions
- Broadly interdisciplinary teams help make good modeling possible

Thank You!