Proactive Contact Tracing

10th Doctoral Researcher Award

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(University of Oxford, The Alan Turing Institute)

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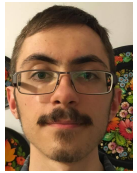
Soren Harnois-Leblanc


Akshay Patel


Bernhard Schölkopf


Olexa Bilanuik

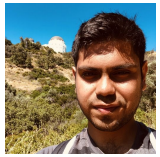

Tegan Maharaj


Joanna Merckx

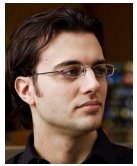

Nanoy Minoyan


Irina Rish


Meng Qu


Nasim Rahaman

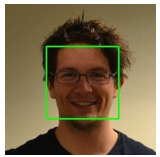

Christopher Pal


Pierre-Luc Carrier


David Buckeridge


Victor Schmidt


Pierre-Luc St Charles


Martin Weiss


Andrew Williams


Yang Zhang


Eilif B. Muller


Joumana Ghosn


Jian Tang


Gaétan Marceau Caron

To **improve the digital contact tracing apps**

To **improve the digital contact tracing apps**

to help **curb the viral spread**

To **improve the digital contact tracing apps**

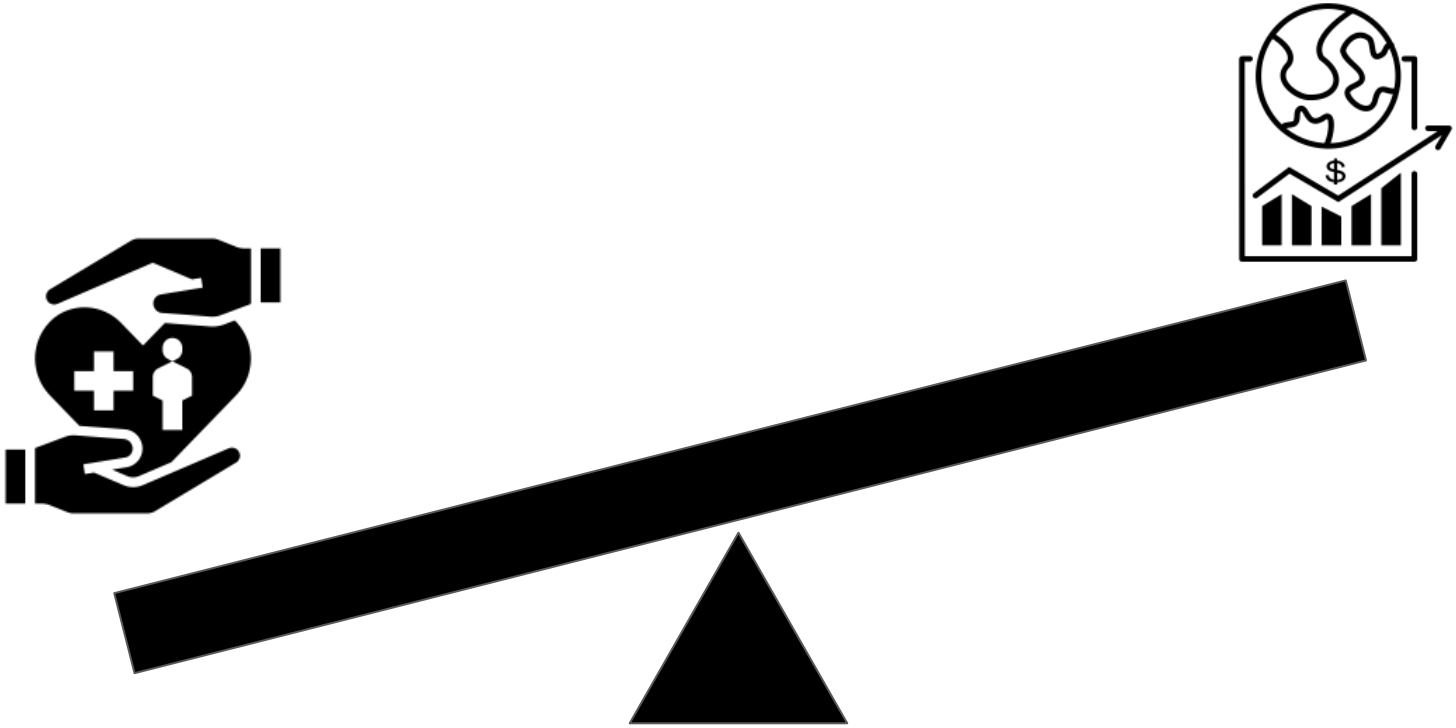
to help **curb the viral spread**

while **minimizing the economic impact**

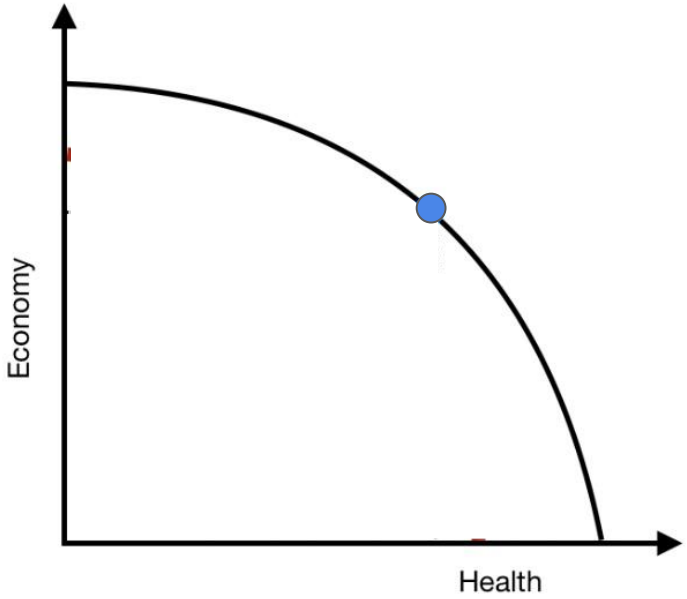
Outline

- **Problem formulation**
- Our approach: Proactive Contact Tracing
  - Framework
  - Privacy Concerns
  - Models
  - Results
- Conclusion and Ongoing work

Health vs Economy

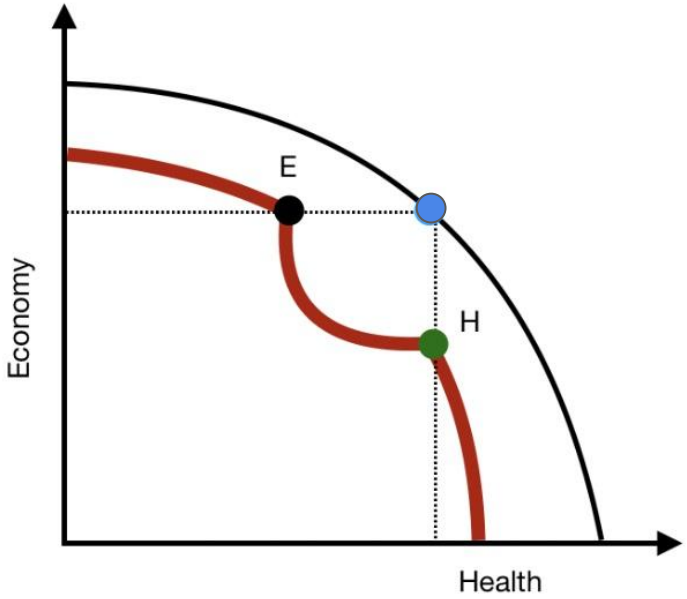


Health vs Economy: Normal times



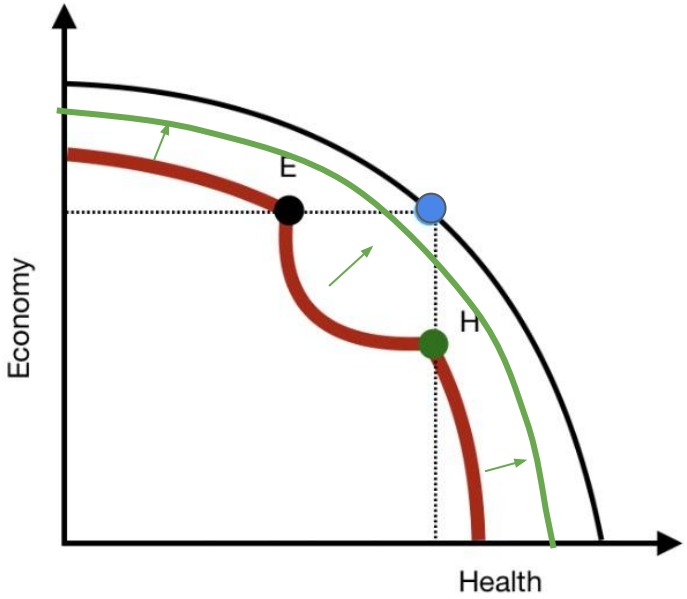
Source: Gans (2020) "Health Before Wealth: Economic Logic

Health vs Economy: Pandemic times



Source: Gans (2020) "Health Before Wealth: Economic Logic

Health vs Economy: Recovery



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Contact Tracing

- **Manual Contact Tracing:** Uses Public Health Experts (PHE) to **email/phone** contacts
  - Class epidemic management
  - Overwhelmed by the scale of pandemic

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    - Recommends quarantine/no quarantine to the users

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- **Digital Contact Tracing:** Uses **smartphone apps** to notify potentially infected contacts

  - **Binary Contact Tracing**:
    - Uses positive/negative test results
    - Recommends quarantine/no quarantine to the users

  - **Proactive Contact Tracing**:
    - Uses individual-features, test results, symptoms, “risk-messages”
    - Recommends Quarantine/reduced contacts/regular contacts

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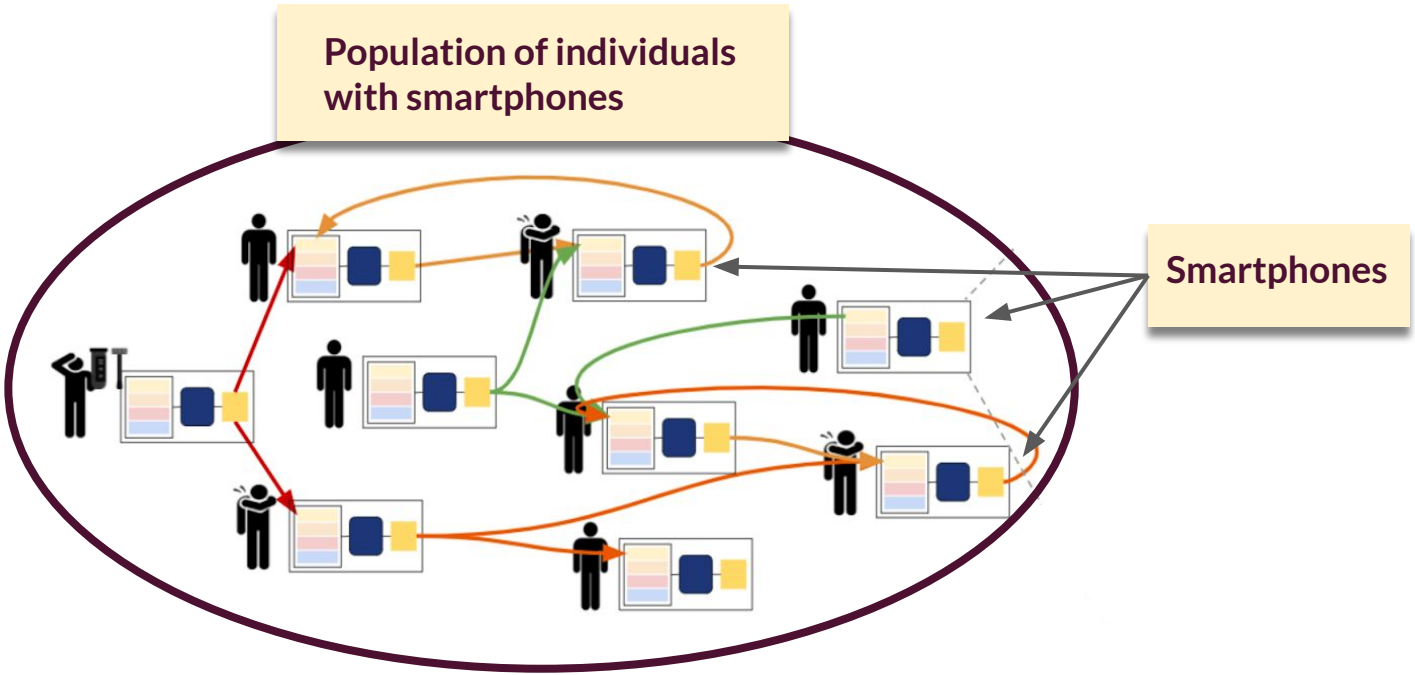
PCT Framework



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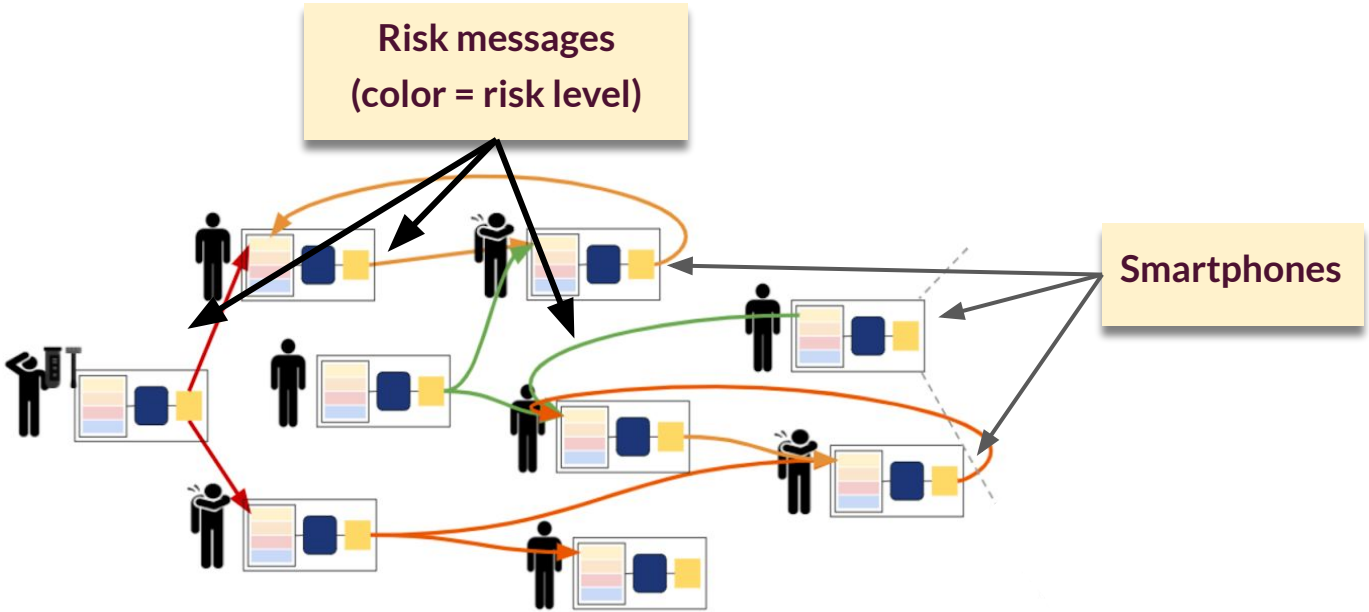

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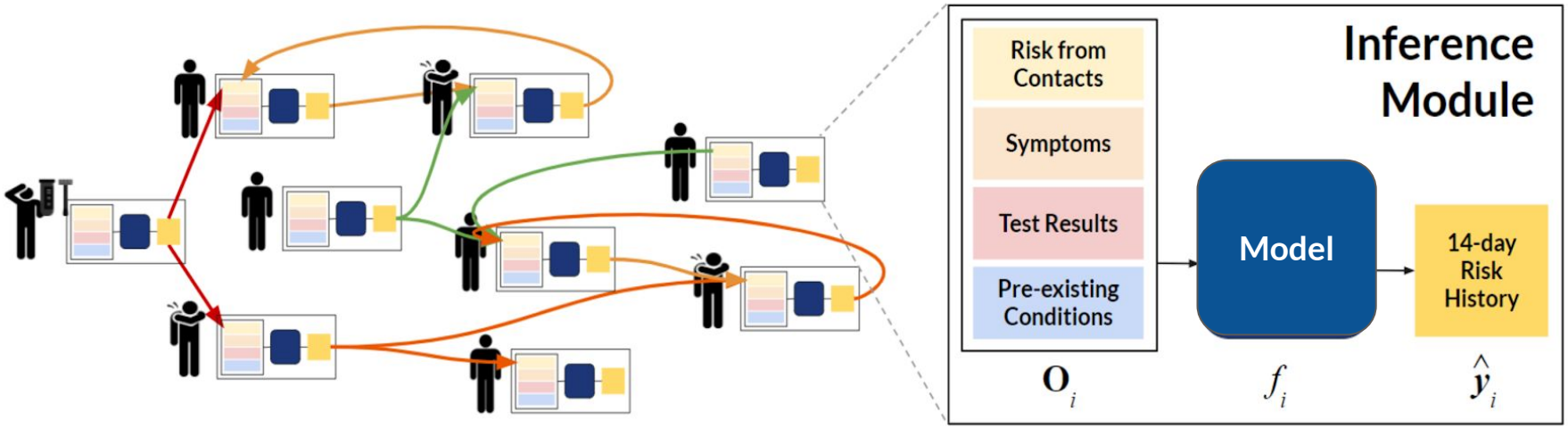

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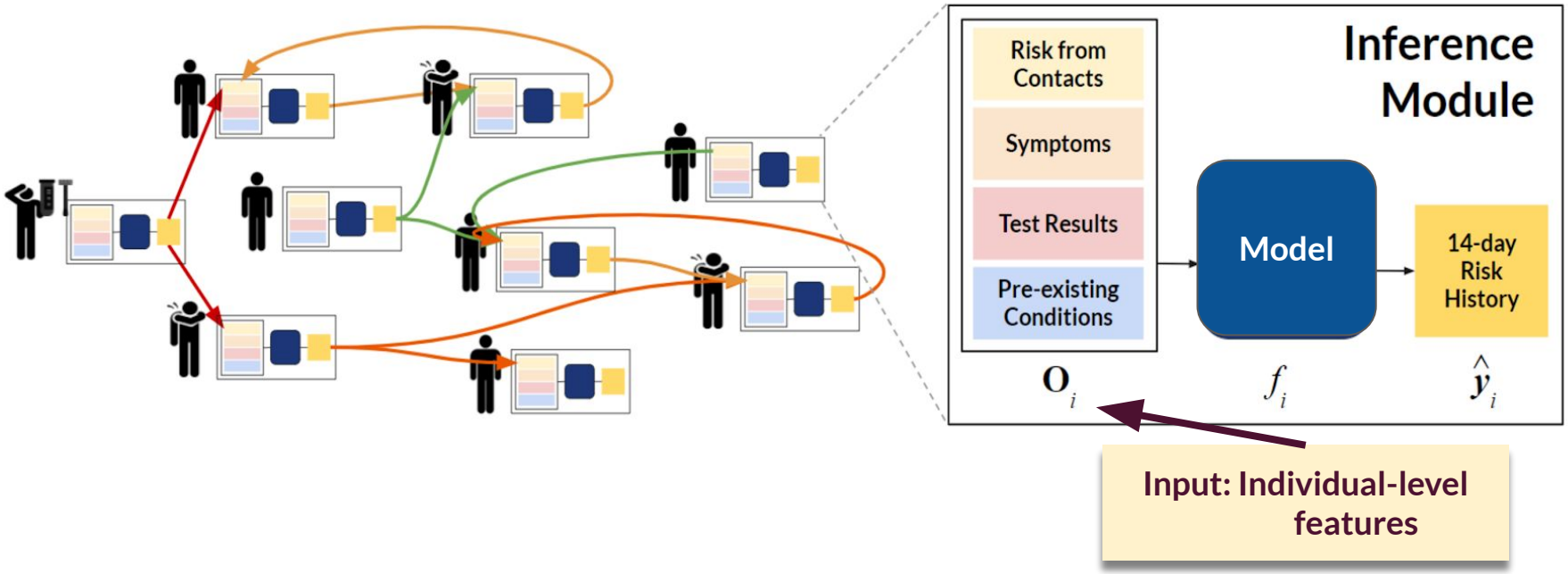

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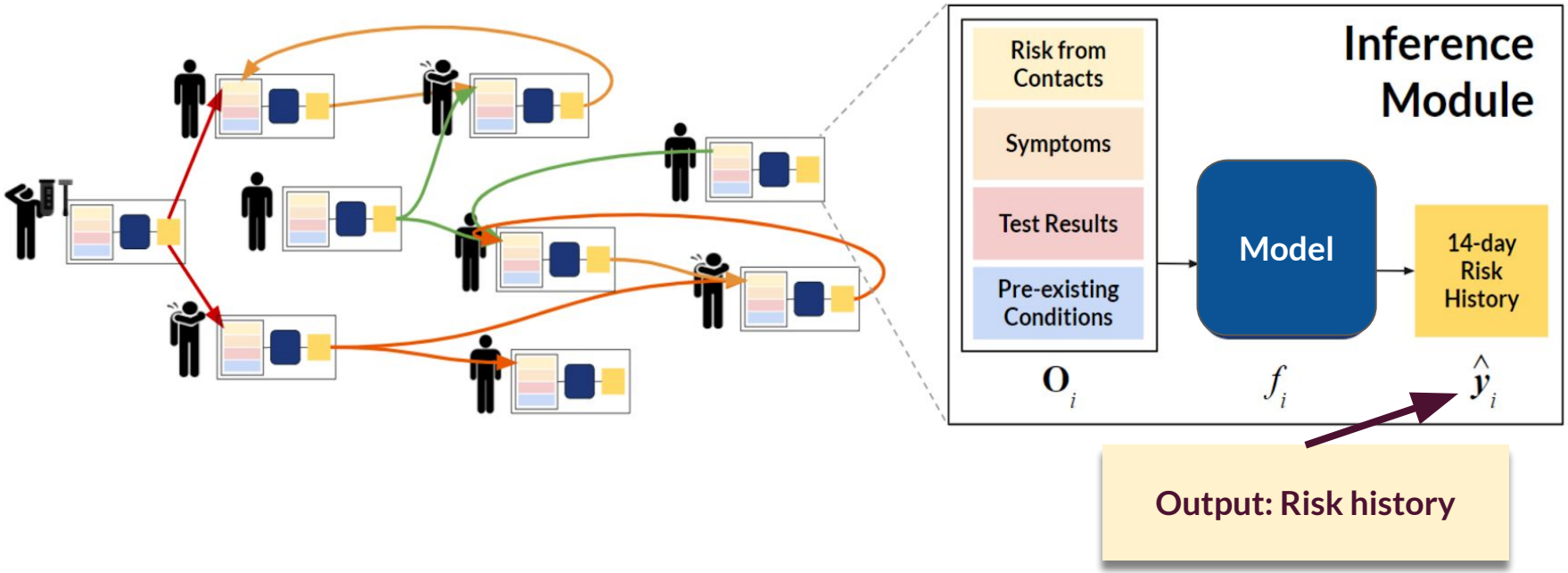

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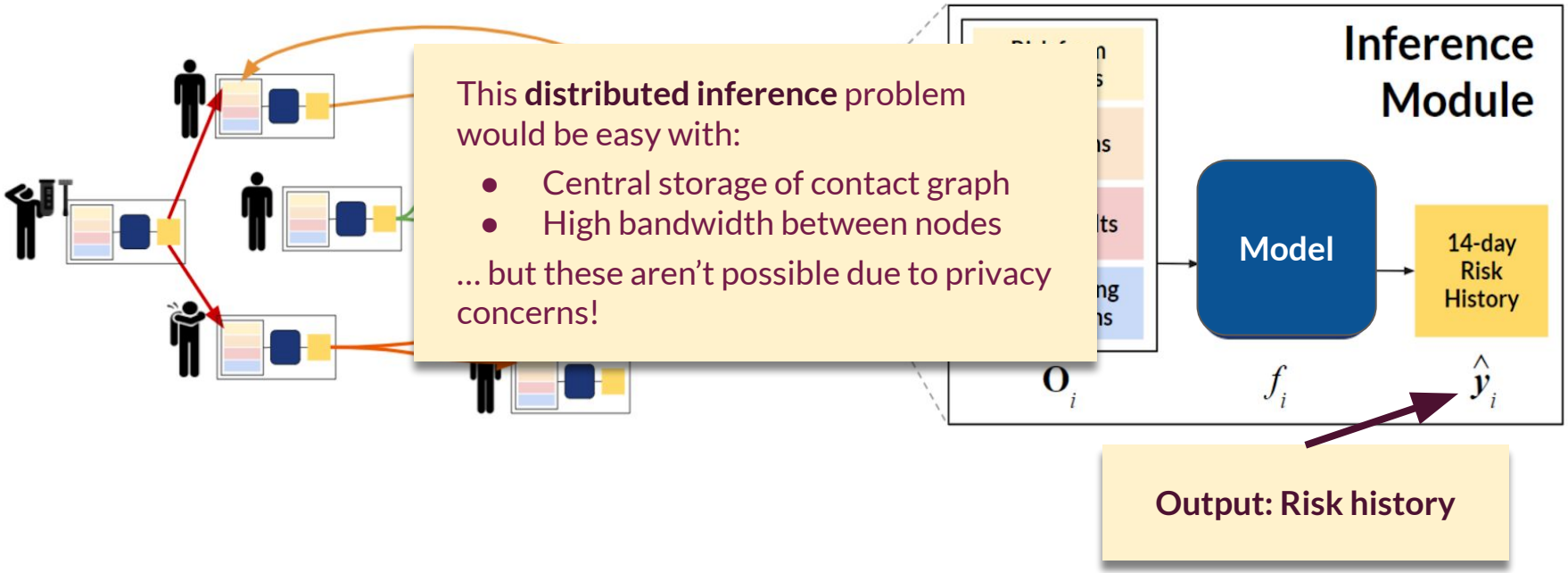

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PCT: Addressing Privacy

- No central storage of contact graph

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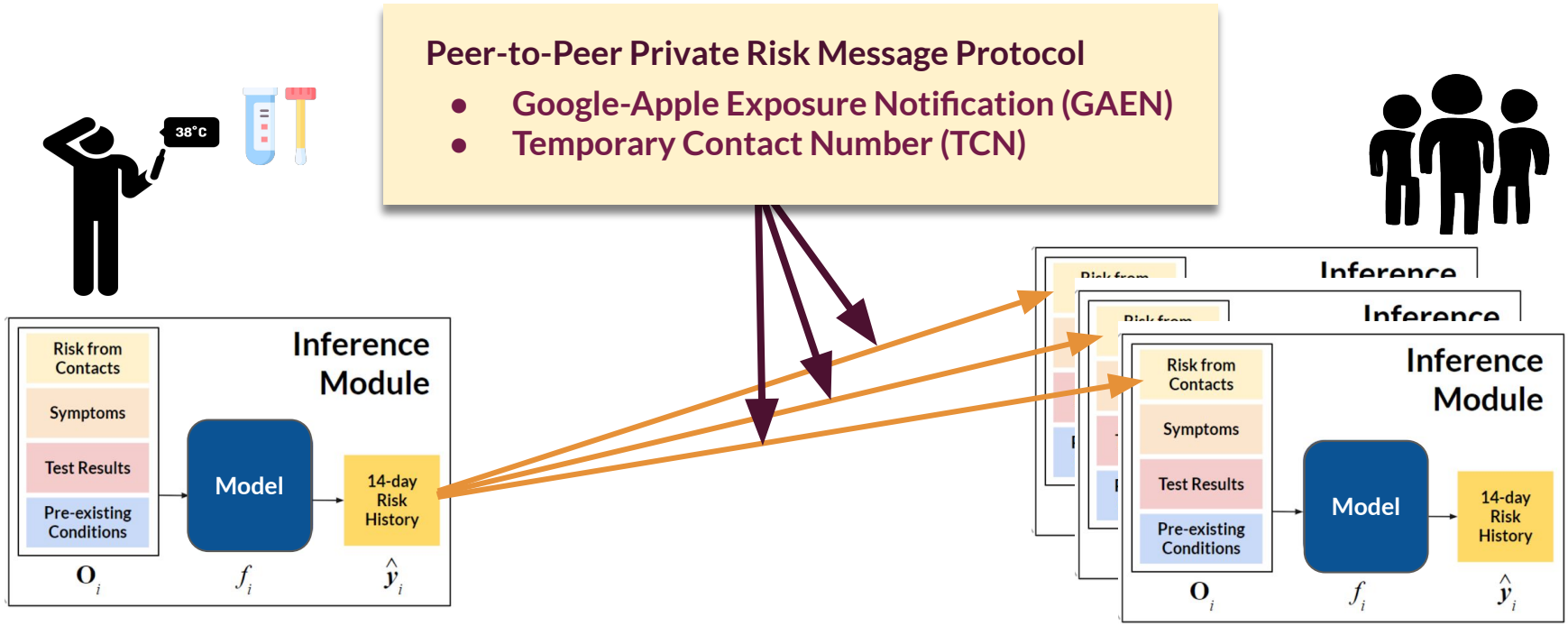
- De-identification and encryption of all data

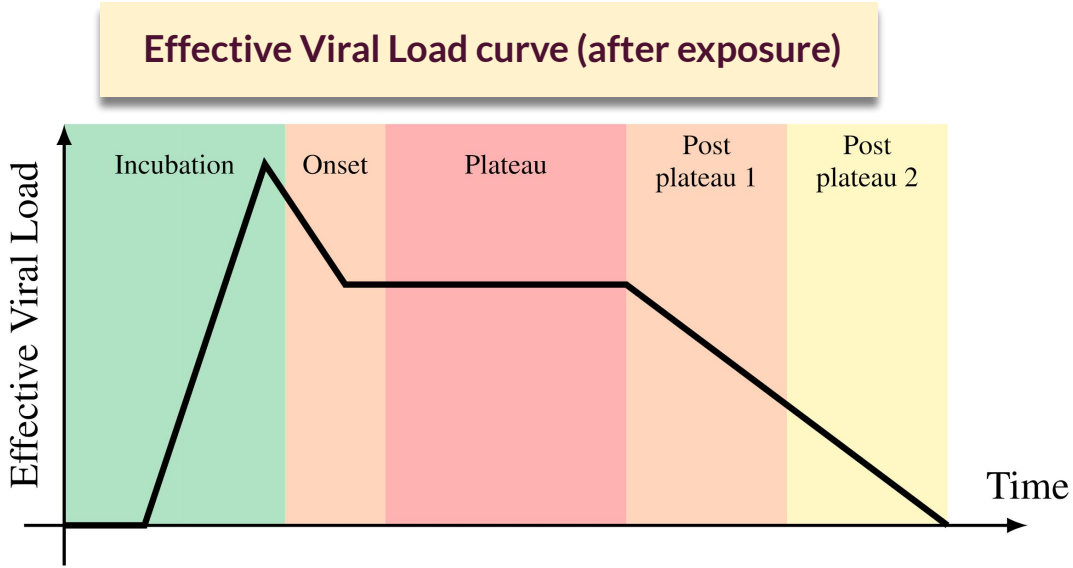
PCT: Addressing Privacy

- No central storage of contact graph
- De-identification and encryption of all data
- User information never leaves the phone

PCT: Risk Messages between phones

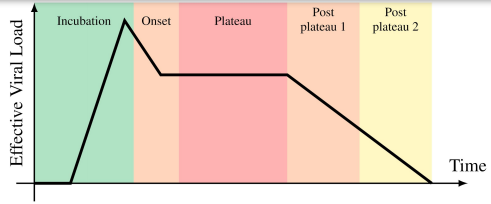


PCT: Risk Messages & Infectiousness



PCT: Risk Messages & Infectiousness

Effective Viral Load curve (after exposure)



Example of target from curve

$\mathbf{y}_i$ Infectiousness over 14 days

.00	.00	.08	.93	.75	.75	.75	.75	.75	.52	.37	.20	.12	.05

PCT: Risk Messages & Infectiousness

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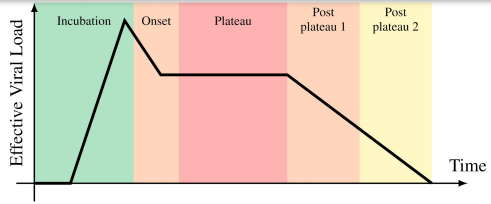
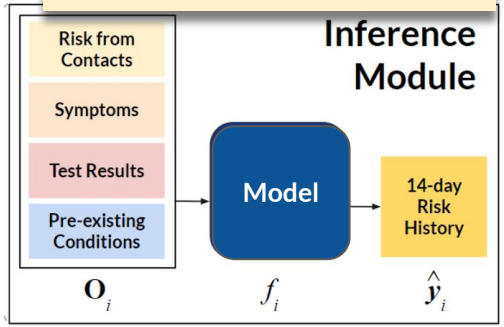


Inference module on each phone



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.00	.00	.08	.93	.75	.75	.75	.75	.75	.52	.37	.20	.12	.05	.00

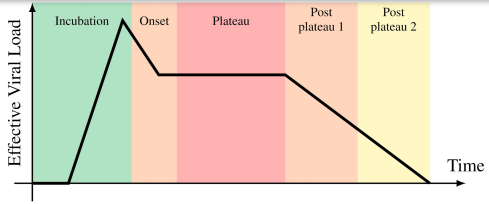
Example prediction

$\hat{\mathbf{y}}_i$ **Estimated Risk History over 14 days**

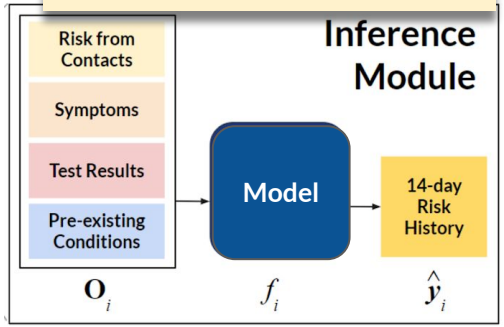
.00	.00	.12	.96	.70	.70	.70	.70	.66	.56	.45	.30	.22	.03	.01

PCT: Risk Messages & Infectiousness

Effective Viral Load curve (after exposure)



Inference module on each phone



Example of target from curve

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.00	.00	.08	.93	.75	.75	.75	.75	.75	.52	.37	.20	.12	.05	.00

Example prediction

$\hat{\mathbf{y}}_i$ Estimated Risk History over 14 days

.00	.00	.12	.96	.70	.70	.70	.70	.66	.56	.45	.30	.22	.03	.01

Example risk levels history

$\hat{\mathbf{y}}'_i$ Estimated Risk History (4-bits quantization)

0	0	2	13	11	7	7	7	7	7	6	4	3	1	1

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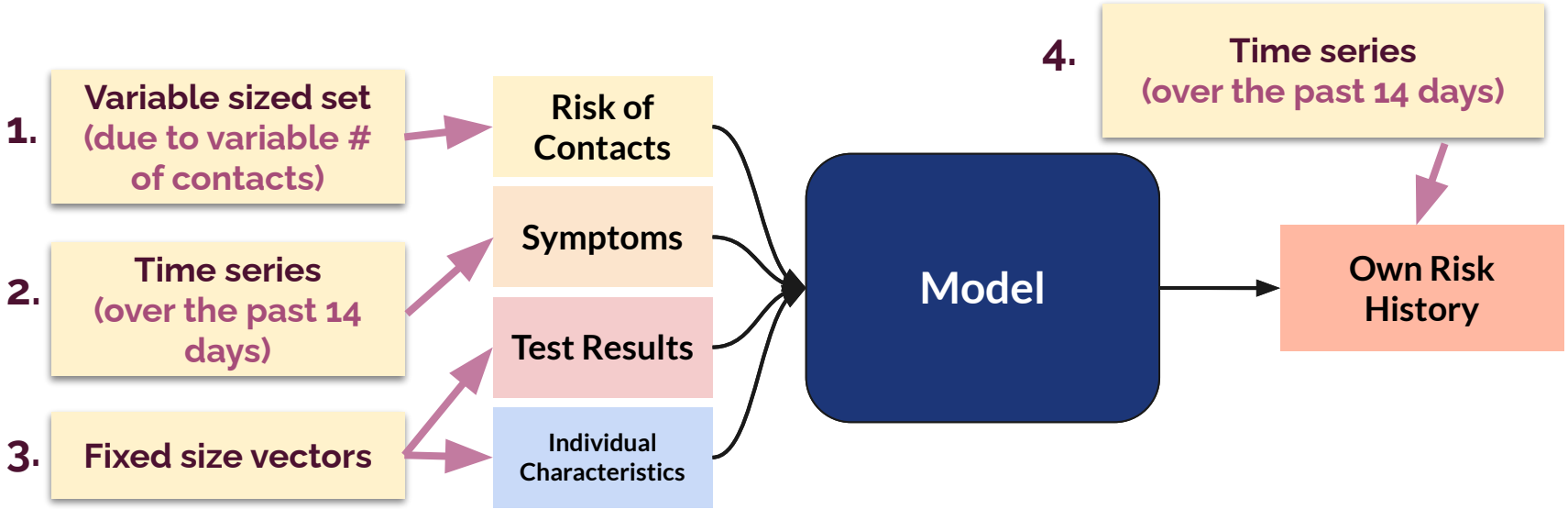
PCT: Model Inputs & Outputs



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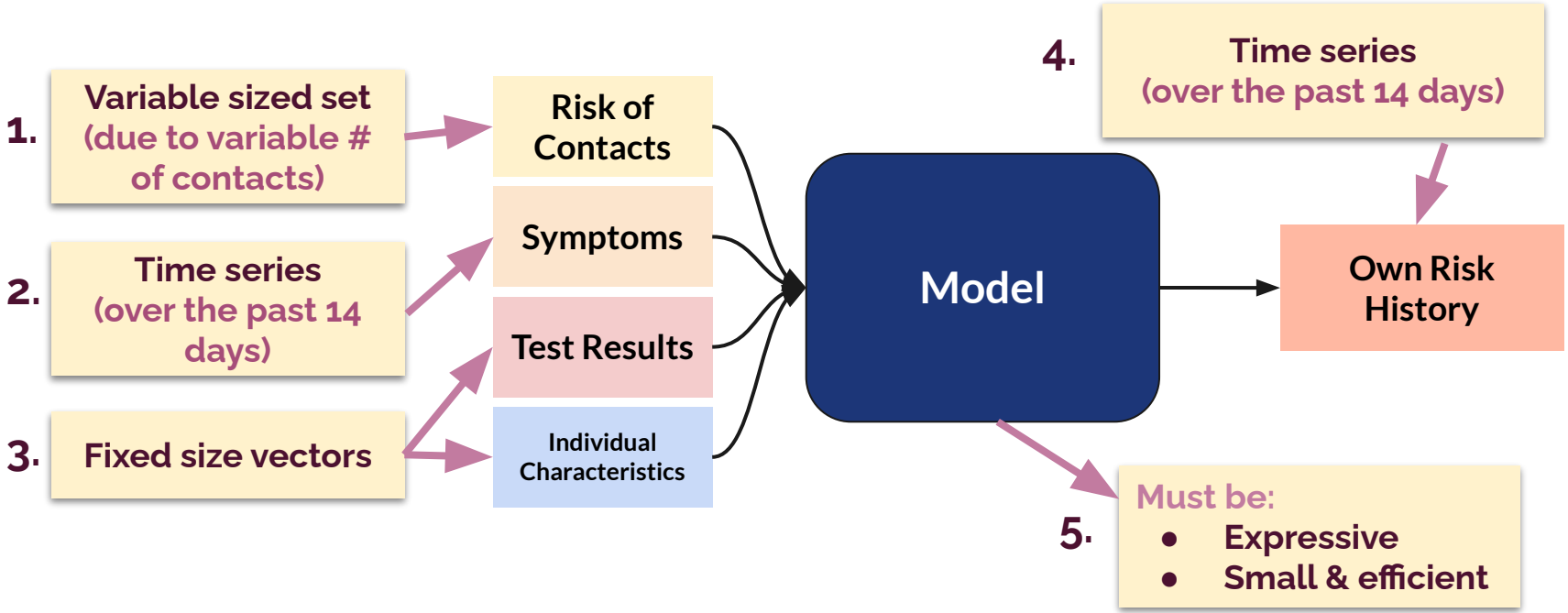
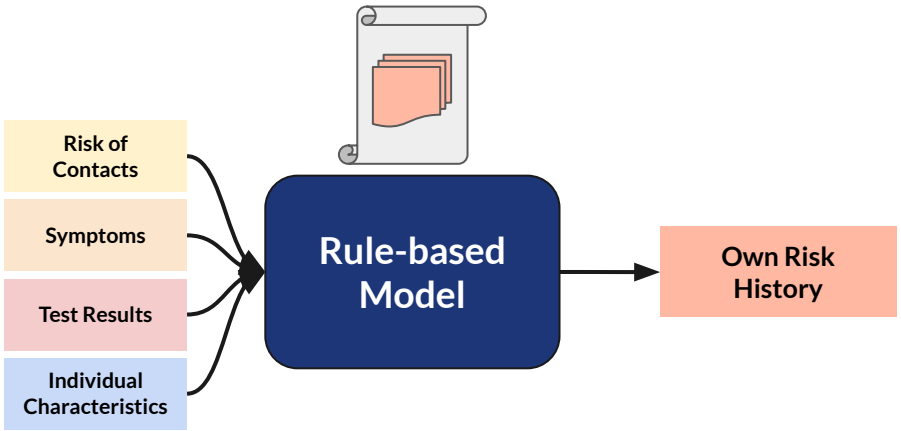


PCT: Rule-based Models

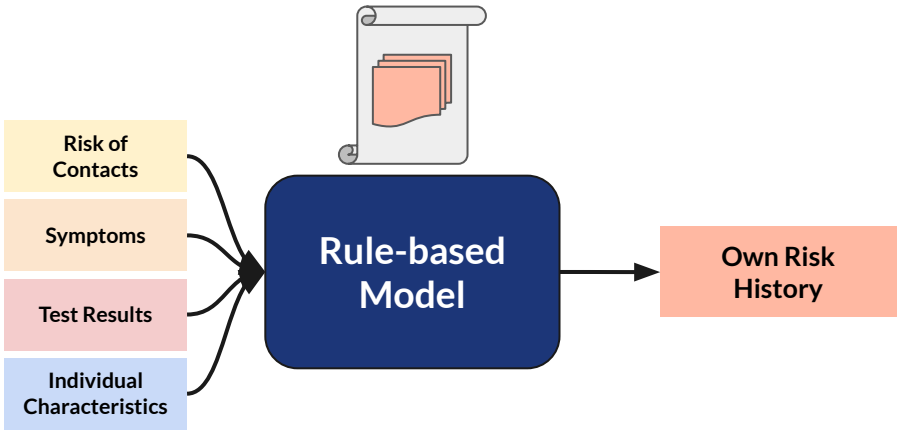
- Rules designed by PHEs



PCT: Rule-based Models

- Rules designed by PHEs

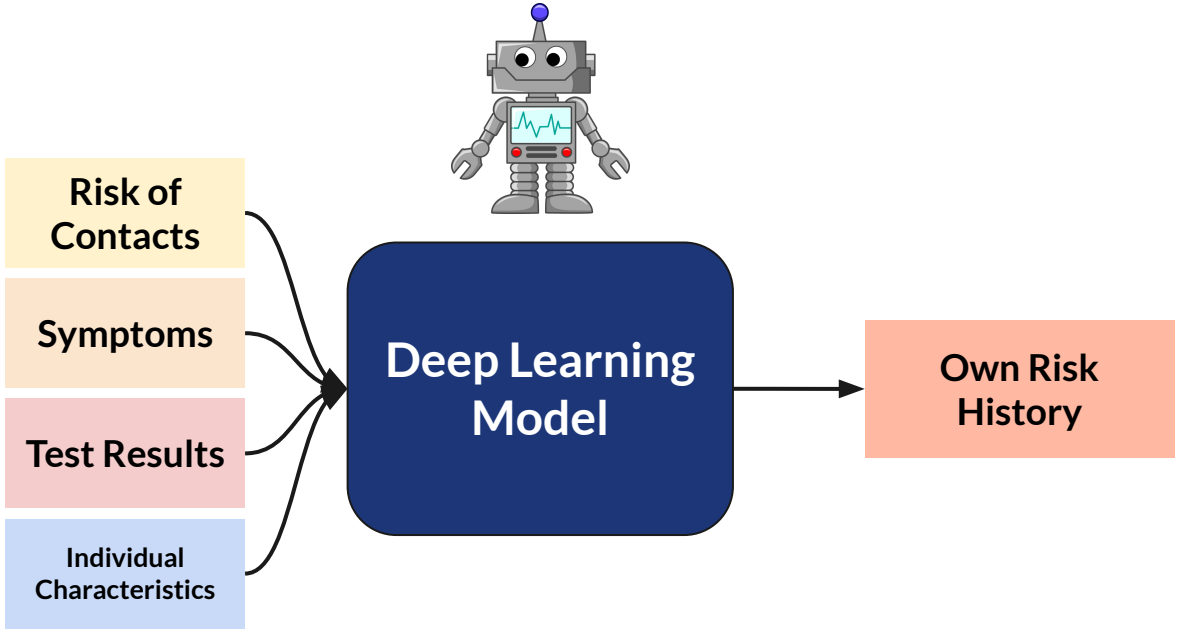
- Gupta et al. 2020 runs experiments on one such heuristic using COVI-AgentSim, an agent-based model



Algorithm 2 *Heuristic-FCT*

function HANDLERECOVERY($\mathbf{S}_d^i$, $\mathbf{T}_d^i$, $M_{i,:}^{:}(:)$, $\mathbf{r}_d^i$)
  Rx $\leftarrow 1$
  if $\sum \mathbf{S}^i_{d,\{:,d:d-d_{max}/2\}} \geq 1$ or $\sum_{d' \in D} \mathbb{1}_{\{\mathbf{T}^i_{d,d'}=+1\}} \geq 1$ **then**
    Rx $\leftarrow 0$
  if $\sum_{j \in \mathcal{N}(i),\ d' \in D,\ d'' \in \{d,d-1,\ldots d-7\}} \mathbb{1}_{\{M^{d'}_{i,j}(d'')=r_{\text{HIGH}}\}} \geq 1$ **then**
    Rx $\leftarrow 0$
  else if $\sum_{j \in \mathcal{N}(i),\ d' \in D,\ d'' \in \{d,d-1,\ldots d-4\}} \mathbb{1}_{\{M^{d'}_{i,j}(d'')=r_{\text{MODERATE}}\}} \geq 1$ **then**
    Rx $\leftarrow 0$
  else if $\sum_{j \in \mathcal{N}(i),\ d' \in D,\ d'' \in \{d,d-1\}} \mathbb{1}_{\{M^{d'}_{i,j}(d'')=r_{\text{MILD}}\}} \geq 1$ **then**
    Rx $\leftarrow 0$
  if Rx $= 1$ **then**
    $\mathbf{r}^i_{d,d:d-d_{max}/2} \leftarrow 0$
  return $\mathbf{r}_d^i$, Rx
function APPLYNEGATIVETEST(ζ_d^i, $\mathbf{r}_d^i$, $\mathbf{T}_d^i$, W)
  $d_n \leftarrow$ day of the latest negative test
  $\mathbf{r}^i_{d,\, d_n - W/2\,:\,d_n + W/2} \leftarrow 0$
  if $\mathbf{r}^i_{d,d} = 0$ **then**
    $\zeta_d^i = 0$
  return $\mathbf{r}_d^i$, ζ_d^i
function COMPUTERISK($\mathbf{T}_d^i$, $\mathbf{S}_d^i$, $M_{i,:}^{:}(:)$, $\mathbf{X}_i$, $\mathbf{r}_{d-1}^i$)
  $W \leftarrow 8$
  $\mathbf{r}_t^i, \zeta_t^i \leftarrow$ TESTRESULTSCOMPUTERISK($\mathbf{T}_d^i$)
  $\mathbf{r}_s^i, \zeta_s^i \leftarrow$ SYMPTOMSCOMPUTERISK($\mathbf{S}_d^i$)
  $\mathbf{r}_m^i, \zeta_m^i \leftarrow$ RISKMESSAGESCOMPUTERISK($M_{i,:}^{:}(:)$)
  $\mathbf{r}_r$, Rx $\leftarrow$ HANDLERECOVERY($\mathbf{S}_d^i$, $\mathbf{T}_d^i$, $M_{i,:}^{:}(:)$, $\mathbf{r}_{d-1}^i$)
  if Rx $= 1$ **then**
    return $\mathbf{r}_r$, 0
  $\mathbf{r}_d \leftarrow \max(\mathbf{r}_t, \mathbf{r}_s, \mathbf{r}_m, \mathbf{r}_{d-1})$ ▷ element-wise maximum
  $\zeta_d^i \leftarrow \max(\zeta_t, \zeta_s, \zeta_m)$
  if $\sum_{d' \in D} \mathbb{1}_{\{\mathbf{T}_{d,d'}=-1\}} \geq 1$ **then**
    $\mathbf{r}_d^i, \zeta_d^i \leftarrow$ APPLYNEGATIVETEST(ζ_d^i, $\mathbf{r}_d^i$, $\mathbf{T}_d^i$, W)
  return $\mathbf{r}_d^i$, ζ_d^i

PCT: AI-based Models



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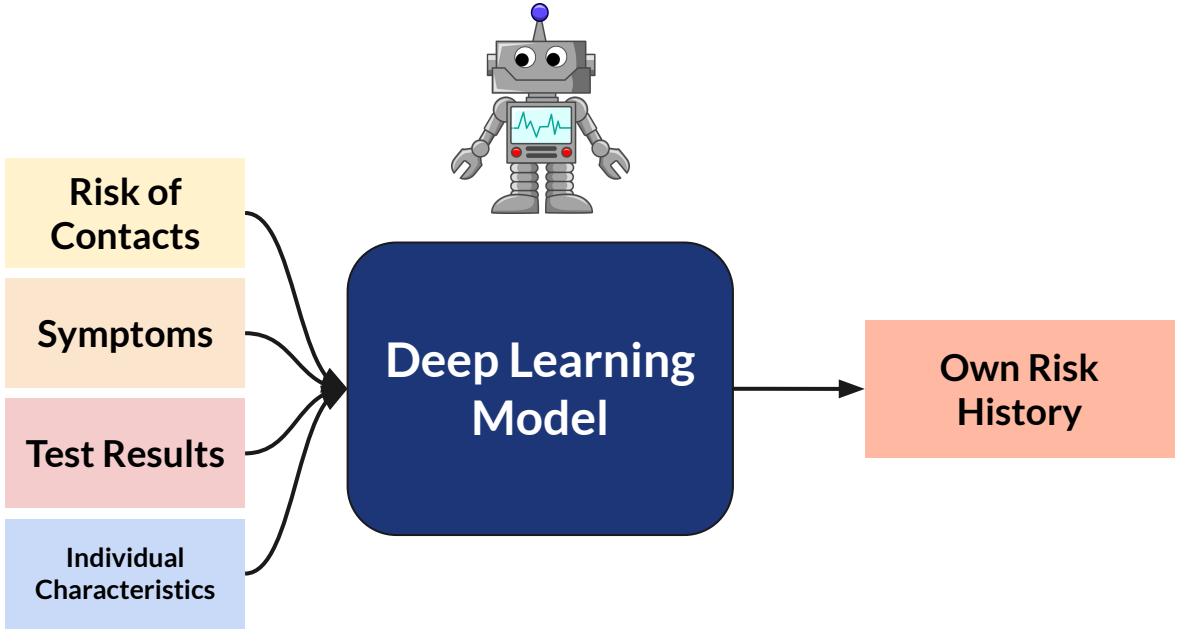
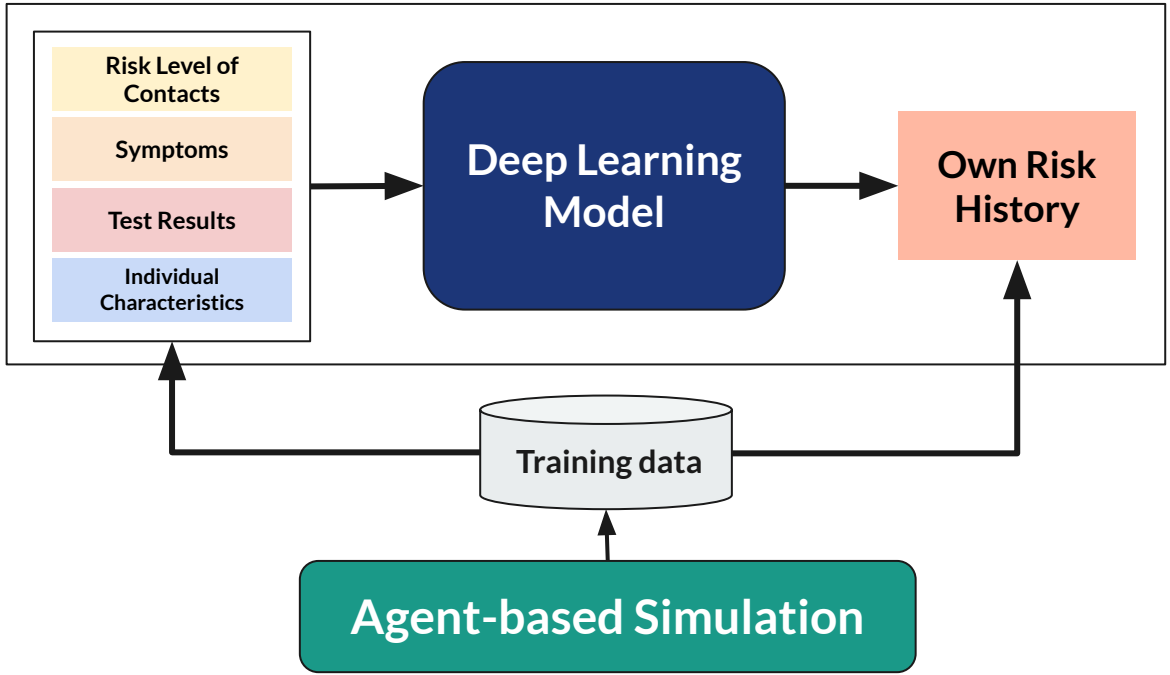


Bengio et al. 2020 (ICLR - Top 20) proposes neural network architecture and training protocol for deep learning based PCT predictor

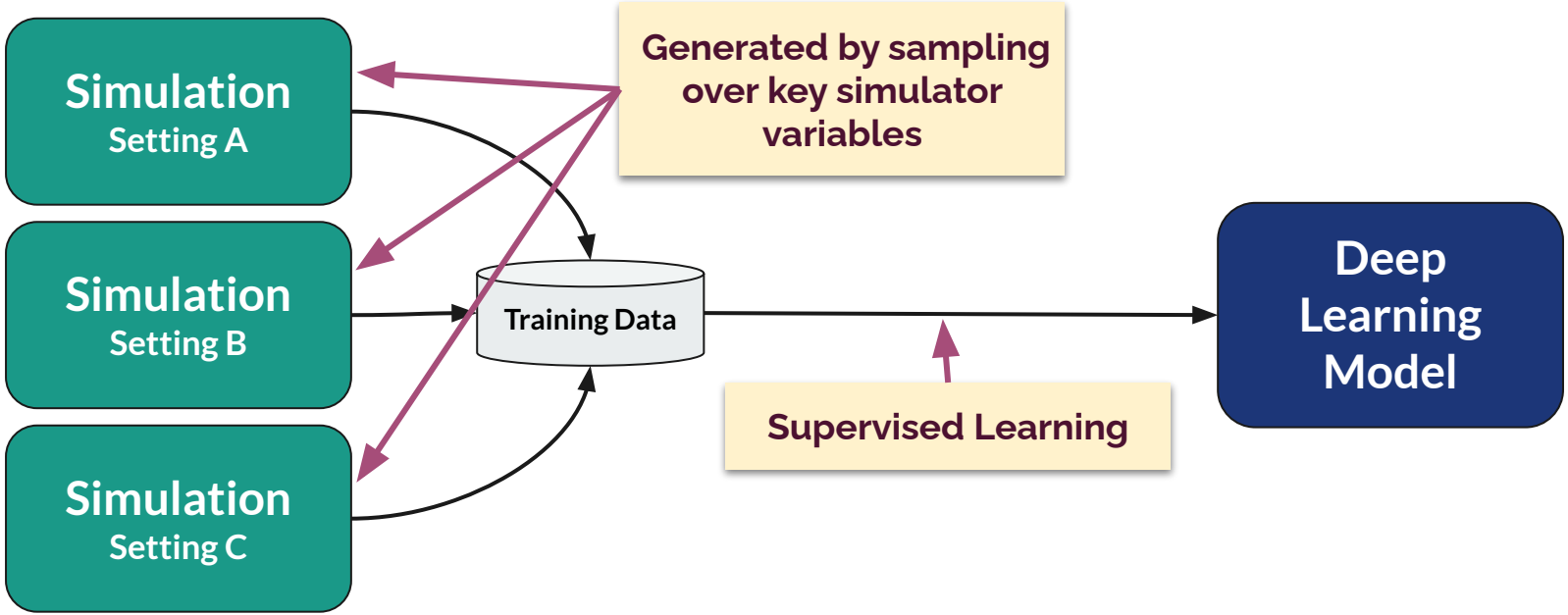
Where does the training data come from?

- Learning from simulations
  - Covi-AgentSim (Gupta et al. 2020) is used as a simulator



But simulator isn't the real world ...

- Domain Randomization:
  - Commonly used in robotics for sim-to-real transfer



But …

And many more challenges were identified and rectified in our ICLR submission (Bengio et al. 2020)

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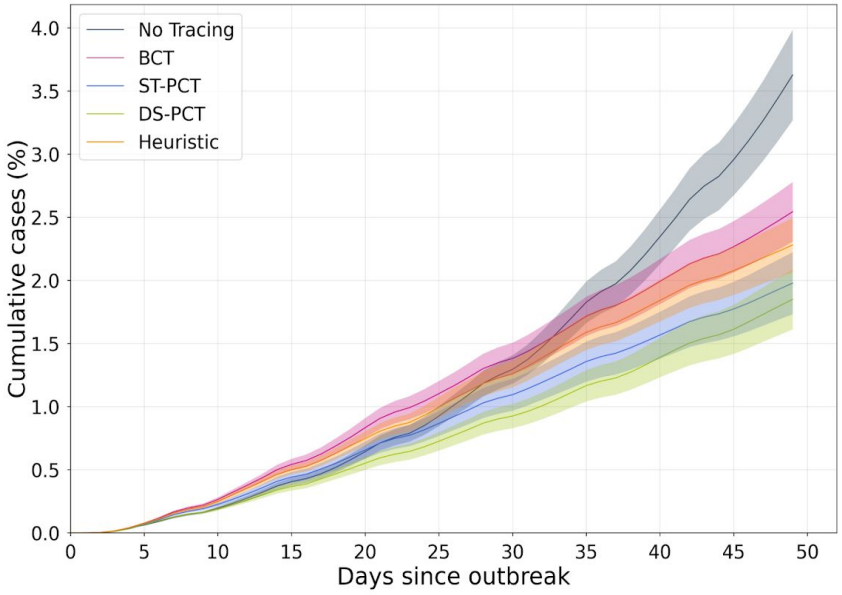
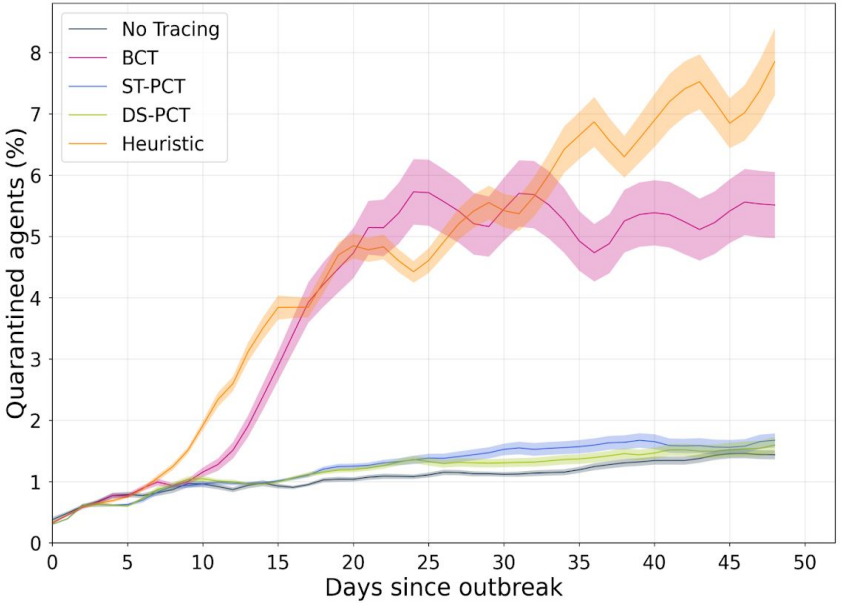
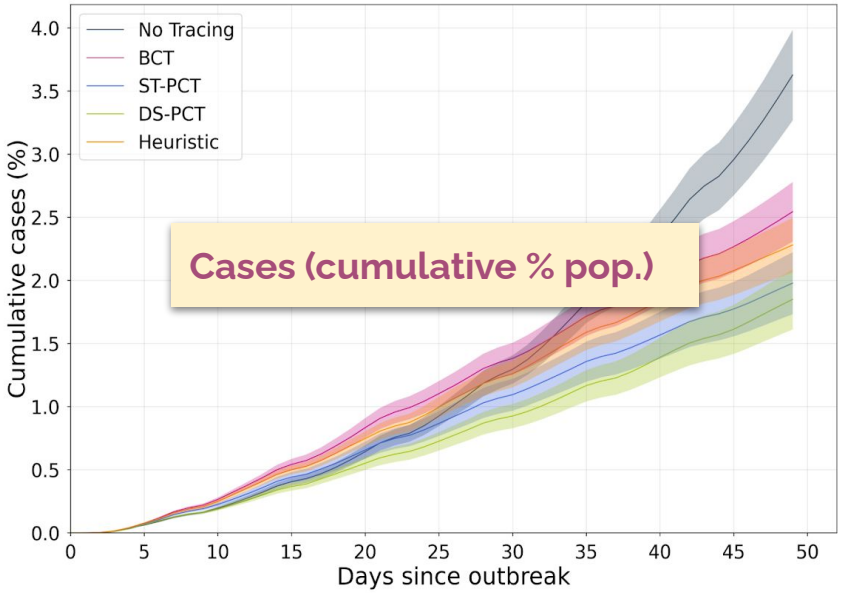
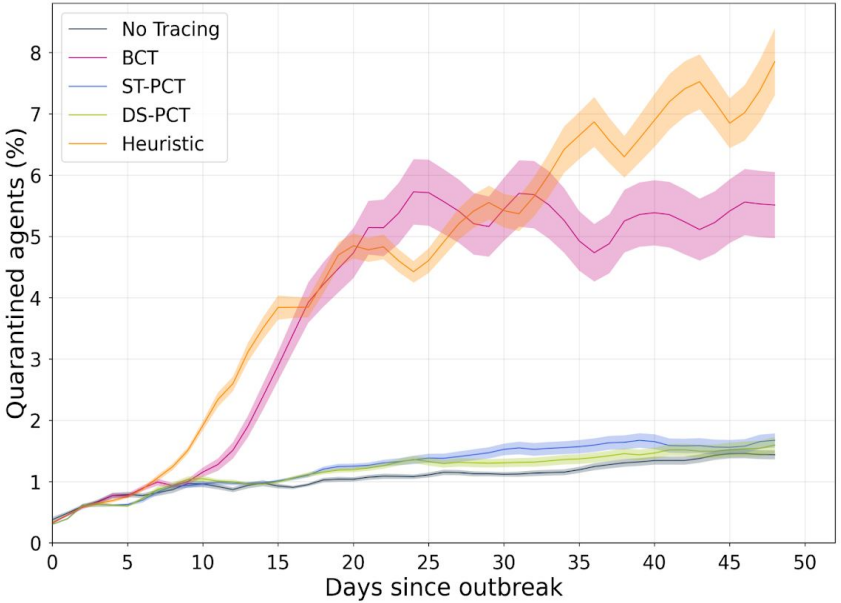




3000 agents, 60% adoption rate, Control: 4-6 average number of contacts per day

PCT: Results





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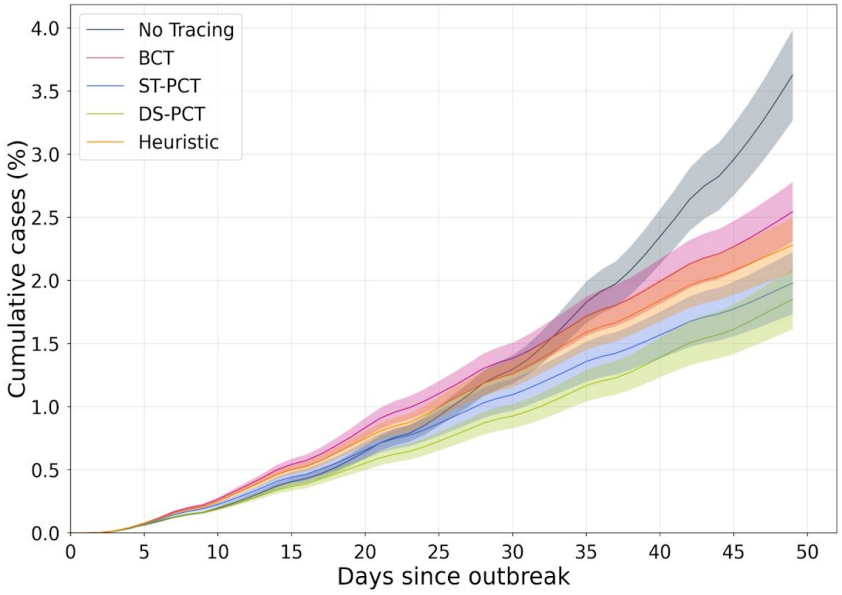

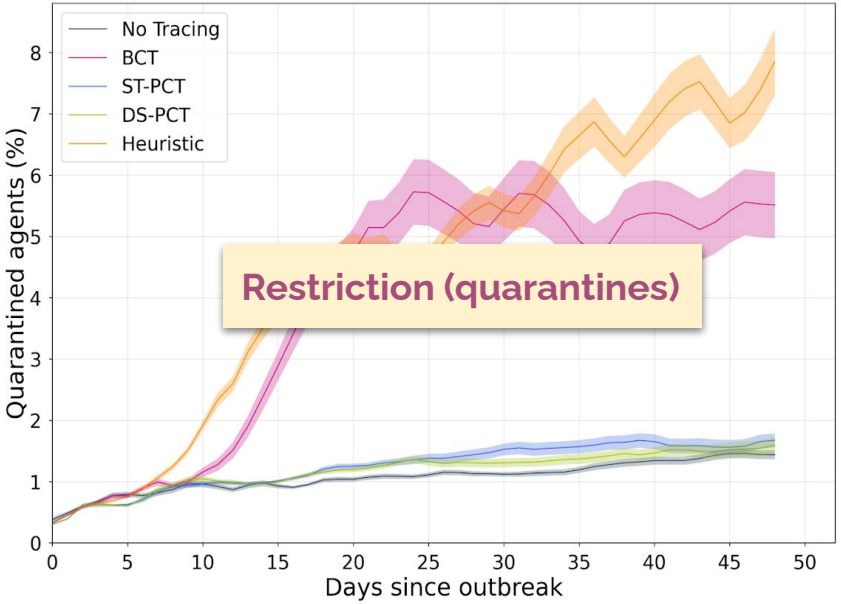

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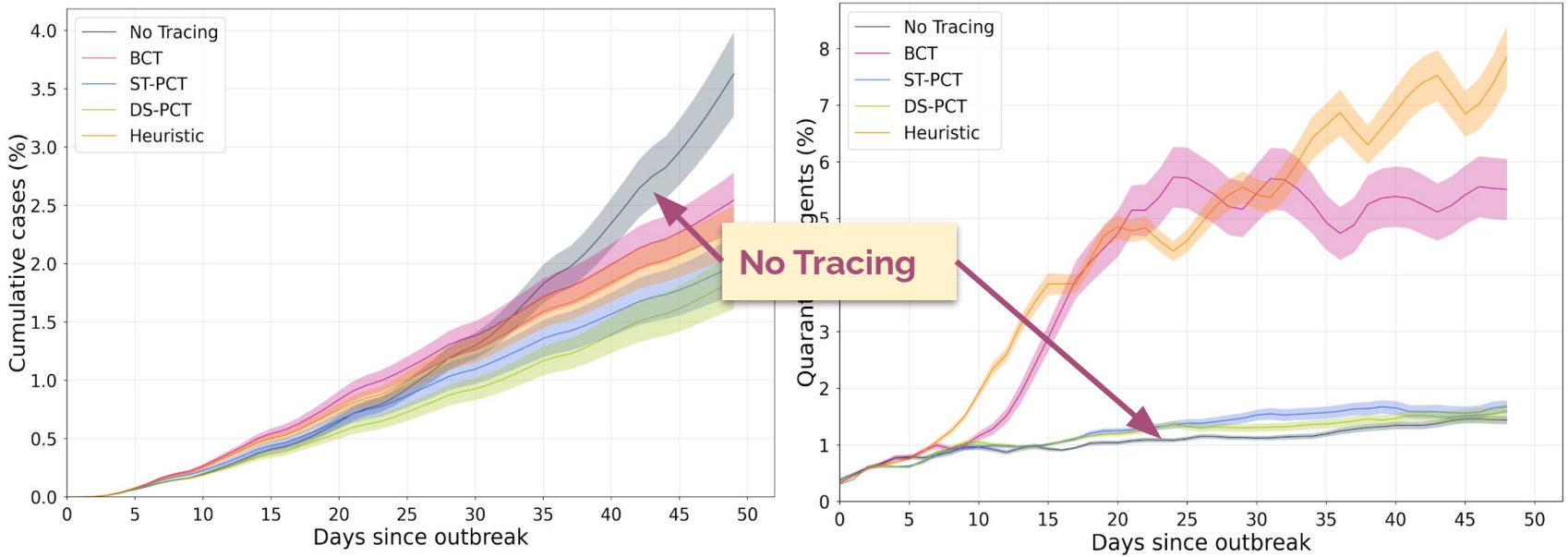

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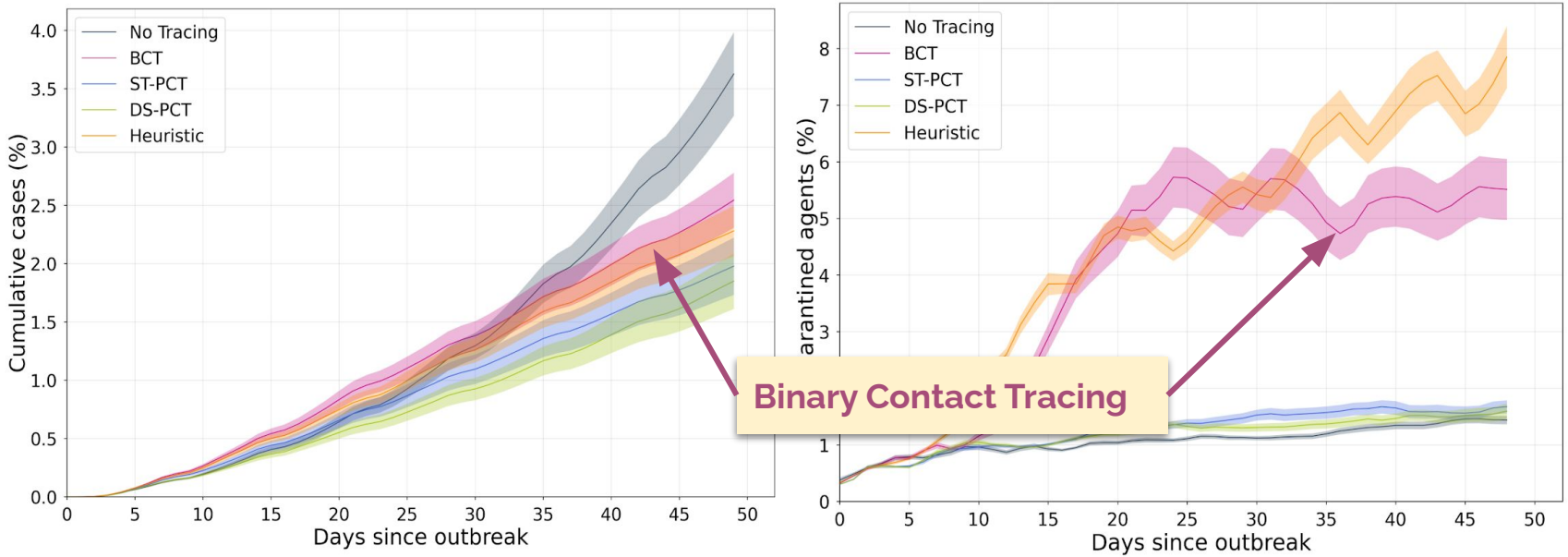

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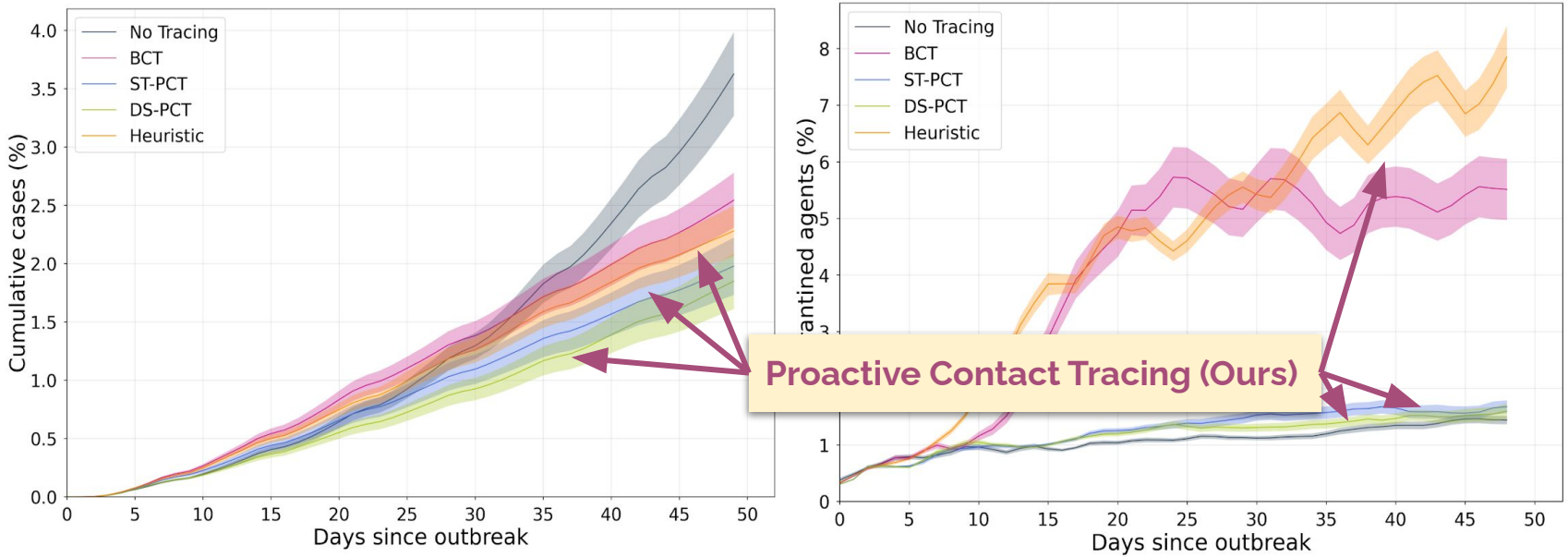

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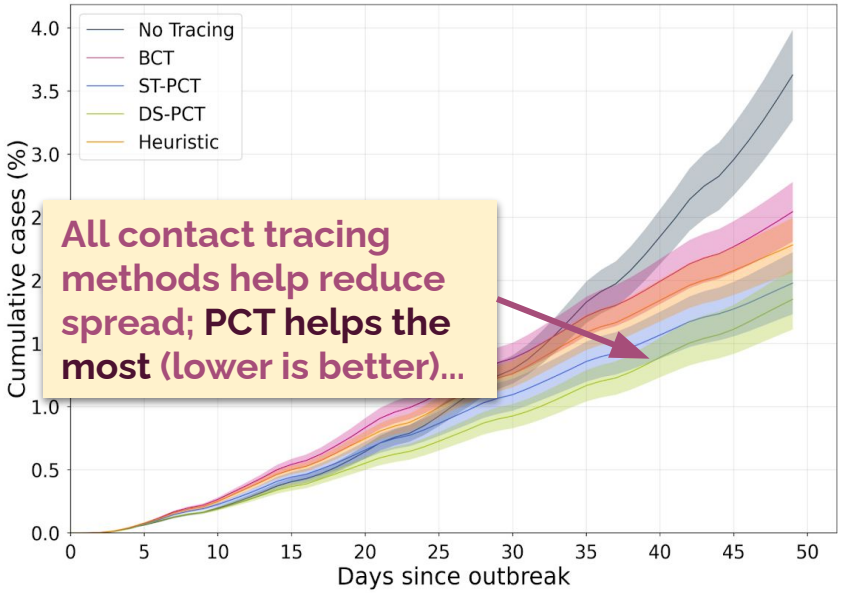
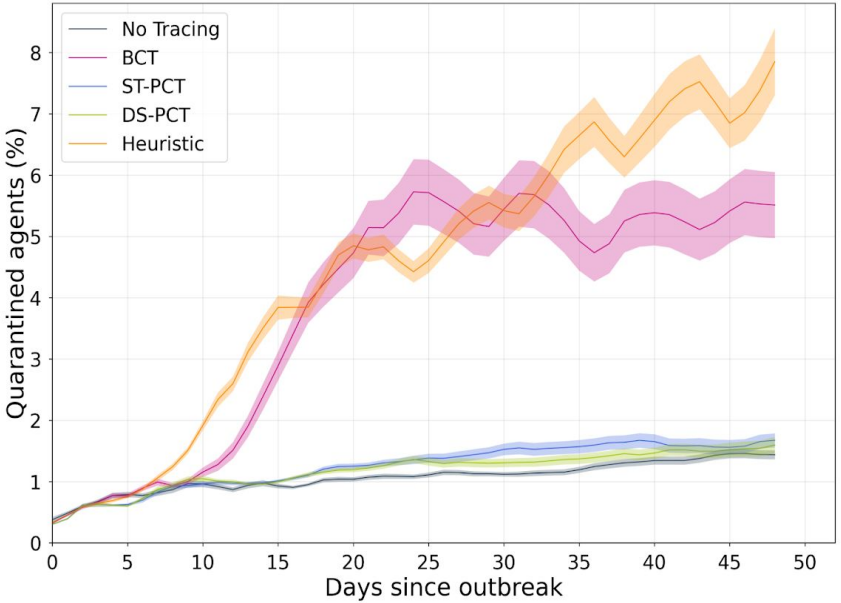
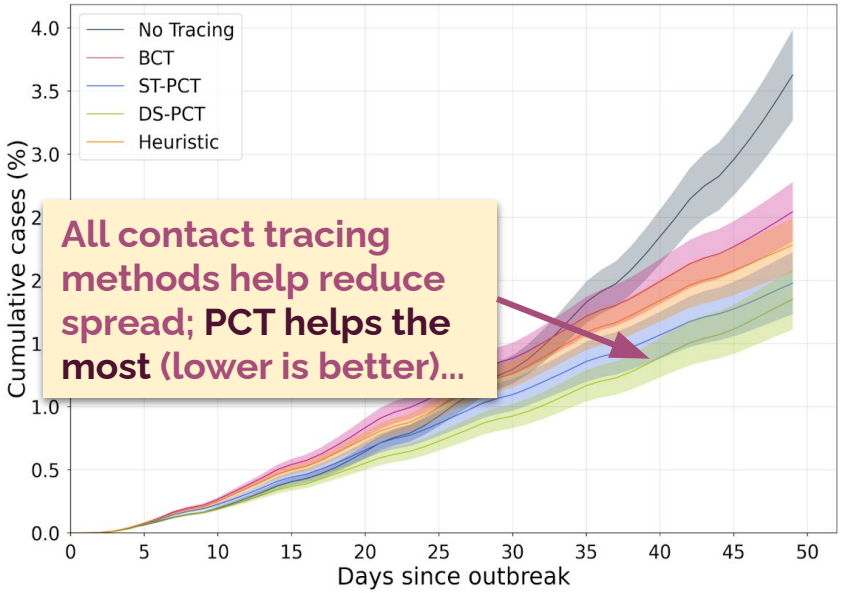
PCT: Results

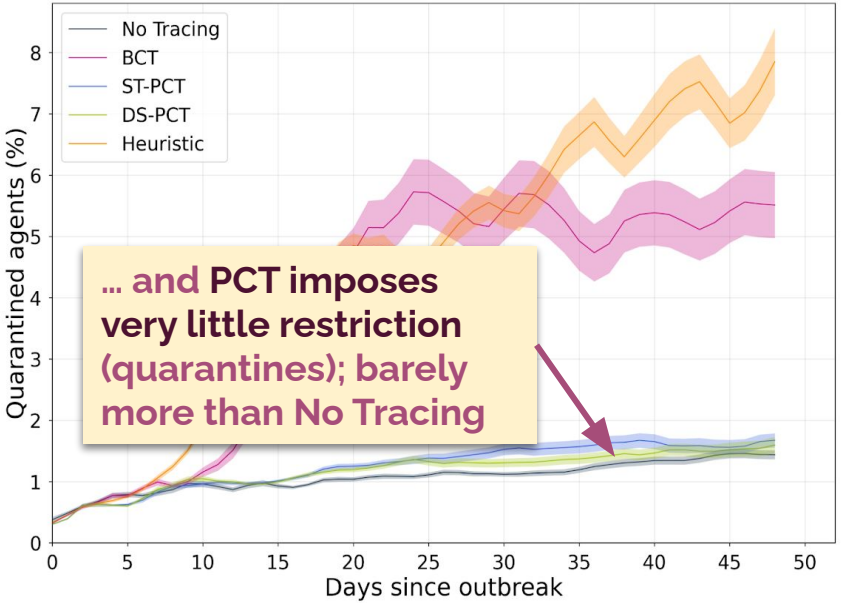




3000 agents, 60% adoption rate, Control: 4-6 average number of contacts per day

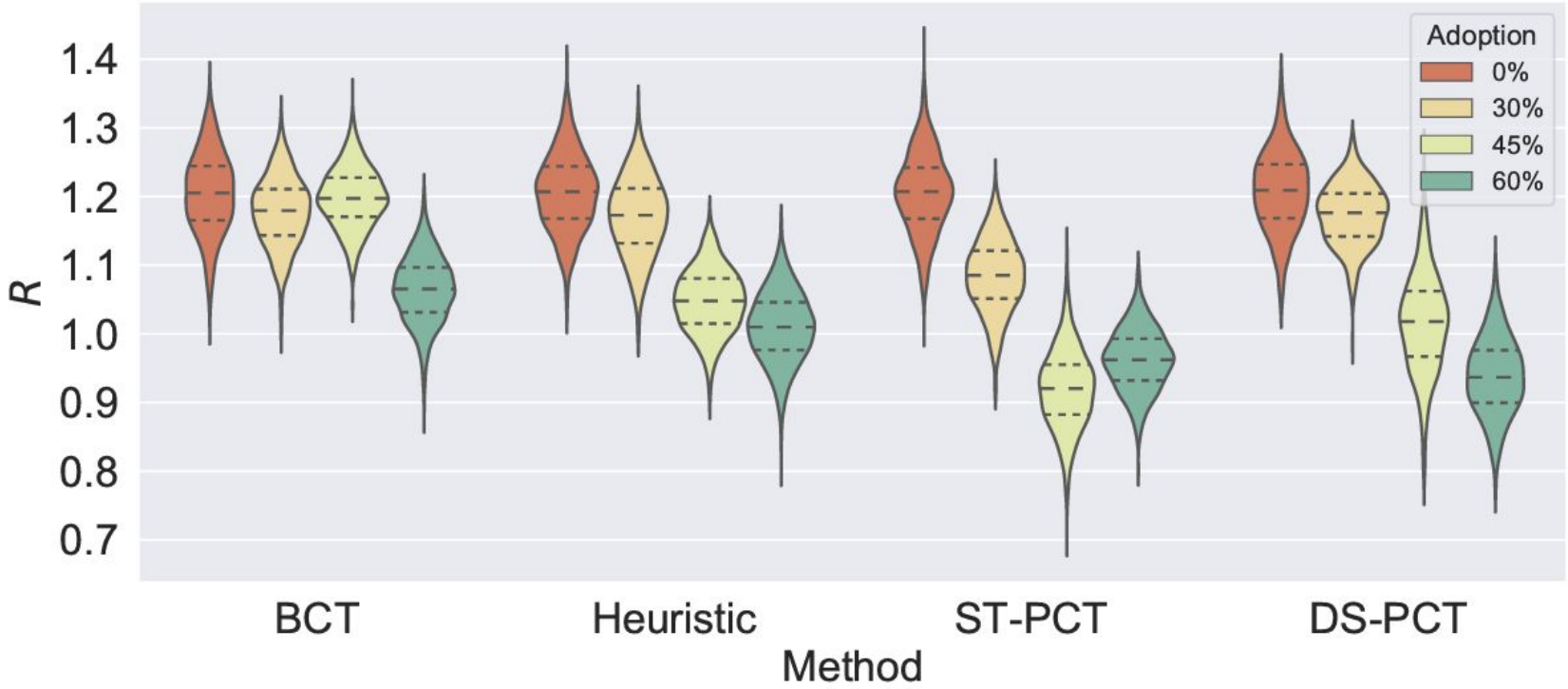
PCT: Results





3000 agents, 60% adoption rate, Control: 4-6 average number of contacts per day

PCT: Results



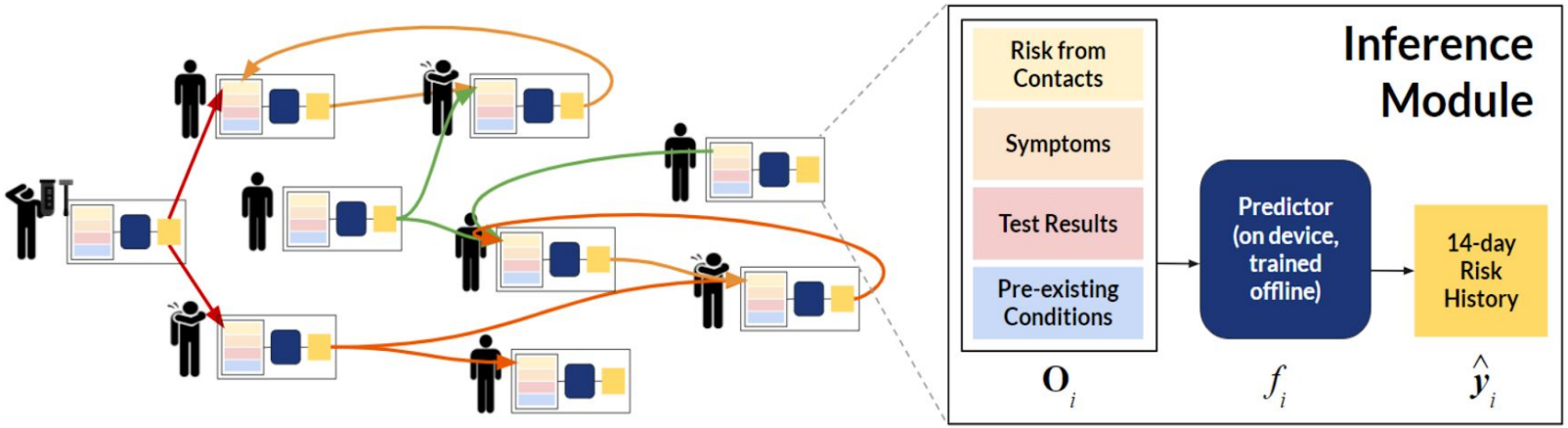
3000 agents, 60% adoption rate, Control: 4-6 average number of contacts per day

Outline

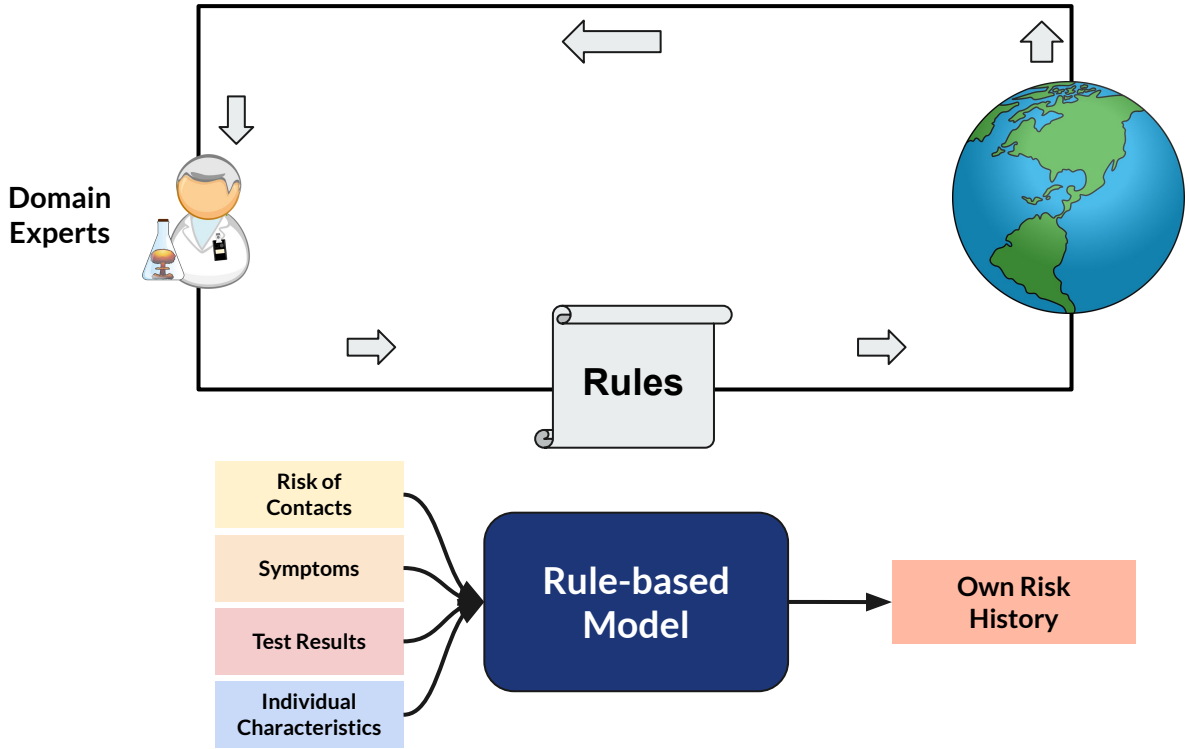
- Problem formulation
- Our approach: Proactive Contact Tracing
  - Framework
  - Privacy Concerns
  - Models
  - Results
- <u>Conclusion and Ongoing work</u>

Conclusions: PCT Framework

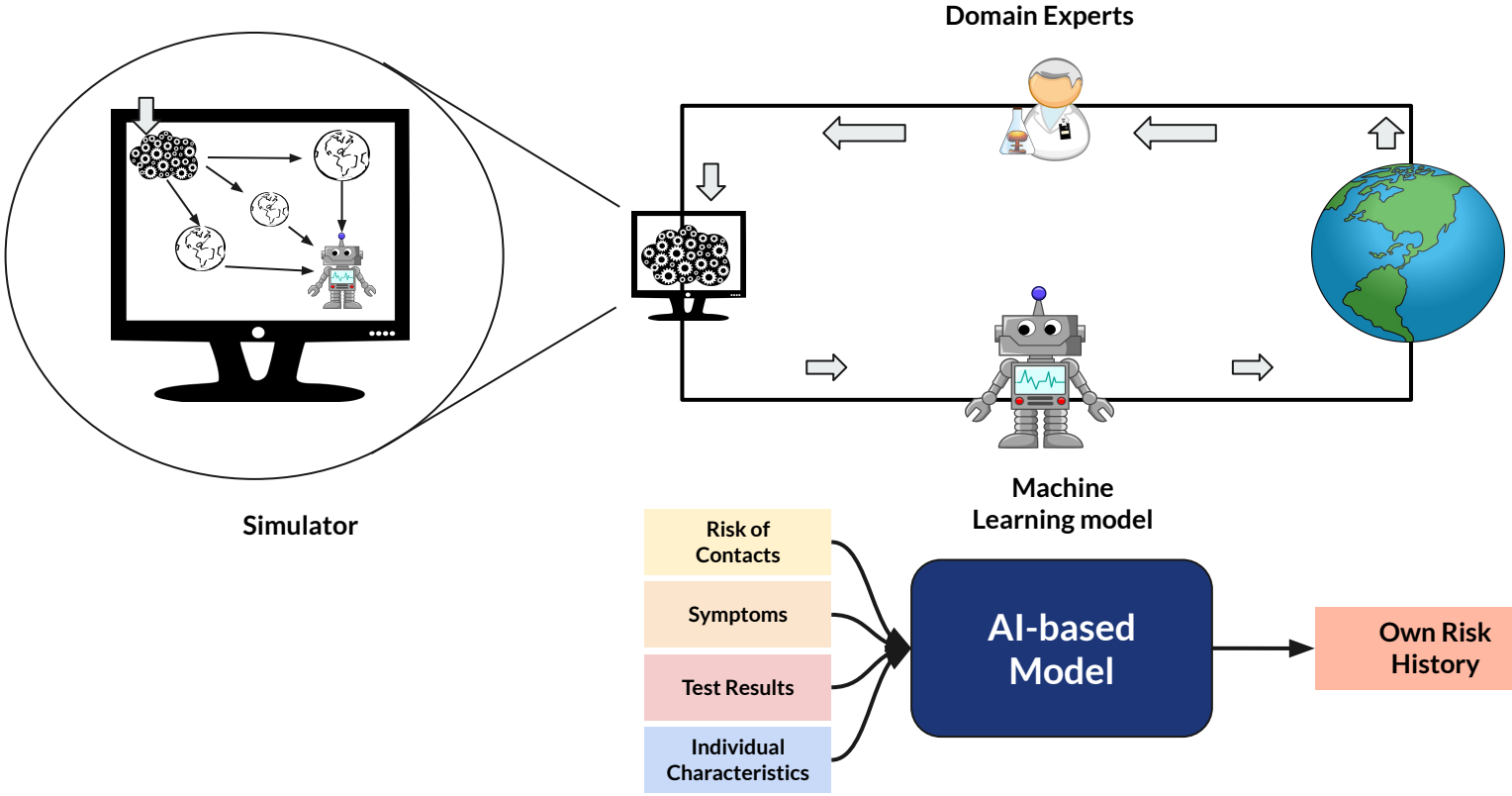
- Common platform for collaboration among
  - epidemiologists,
  - computer scientists,
  - privacy experts,
  - user behavior researchers
- Designed to address privacy concerns



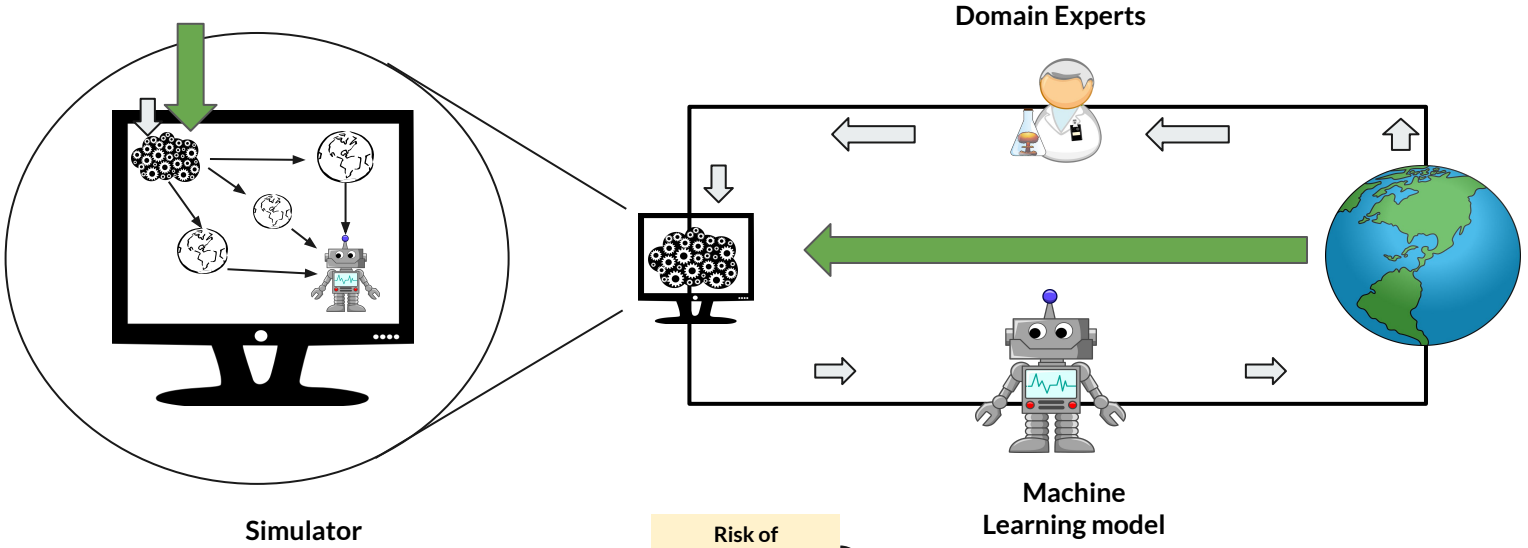
Conclusions: Rule-based PCT



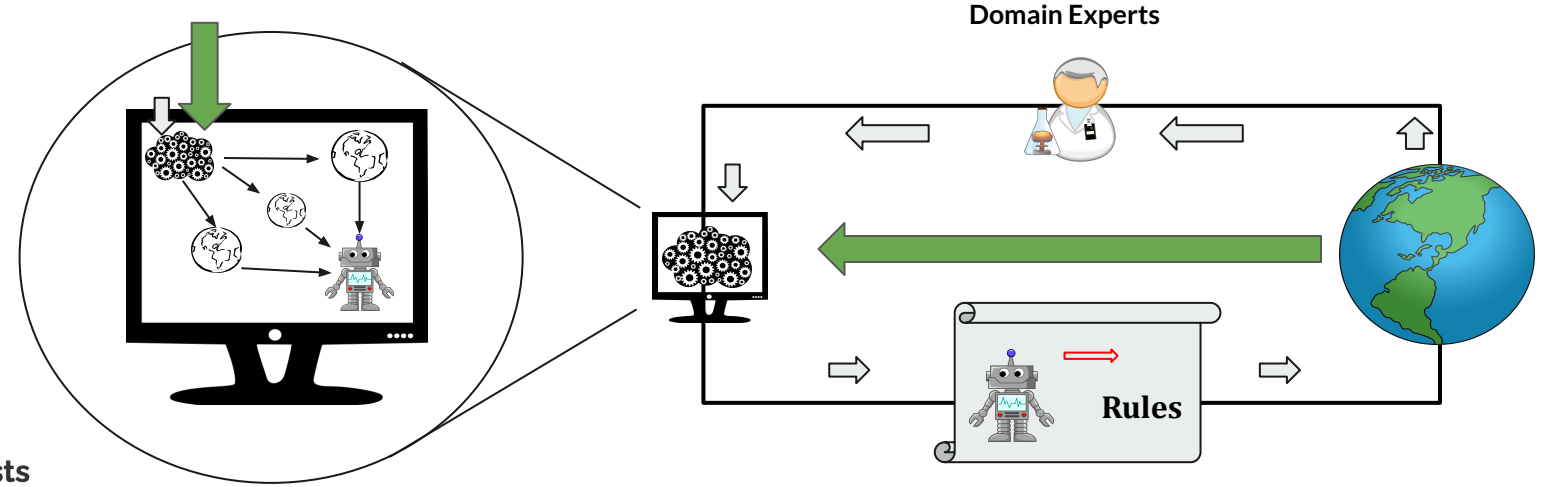
Conclusions: AI-based PCT



Conclusions: AI-based PCT

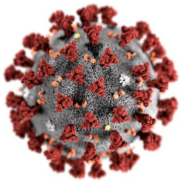


Blog: Responsible AI-based PCT



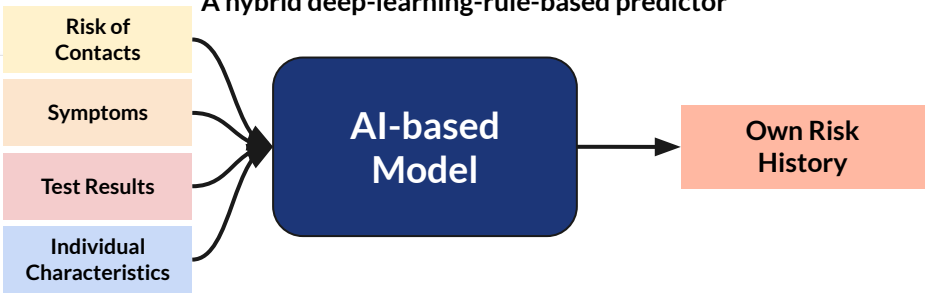
Blog Posts

2021



Contact tracing as a personalization framework

- *Why do we need contact tracing?*
- *Search for a unified framework*
- *Framework in practice*
- *Deep learning for the framework*
- *Limitations and Open Questions*
- *Why should we care now?*



COVI App

Montreal

Testing the public's trust: Quebec premier mulls adopting contact-tracing app

Protecting users' privacy integral part of COVI app's design, says CEO of Montreal's AI institute

Kate McKenna · CBC News · Posted: May 19, 2020 6:46 PM ET | Last Updated: May 19, 2020

Thank you & Resources

Slides:
www.pgupta.info/talks

Blog:
www.pgupta.info/blog

COVI White Paper:
https://arxiv.org/abs/2005.08502

Smartphone App:
https://mila.quebec/en/project/covi/

COVI-AgentSim Paper:
https://arxiv.org/pdf/2010.16004.pdf

COVI-AgentSim Code:
https://github.com/mila-iqia/COVI-AgentSim

COVI-ML Paper:
https://arxiv.org/pdf/2010.12536.pdf

COVI-ML Code:
https://github.com/mila-iqia/COVI-ML

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Policy Makers