MECHANISM DESIGN FOR SOCIAL GOOD:

MAXIMISING THE UTILITY OF A LIMITED NUMBER OF COVID TESTS

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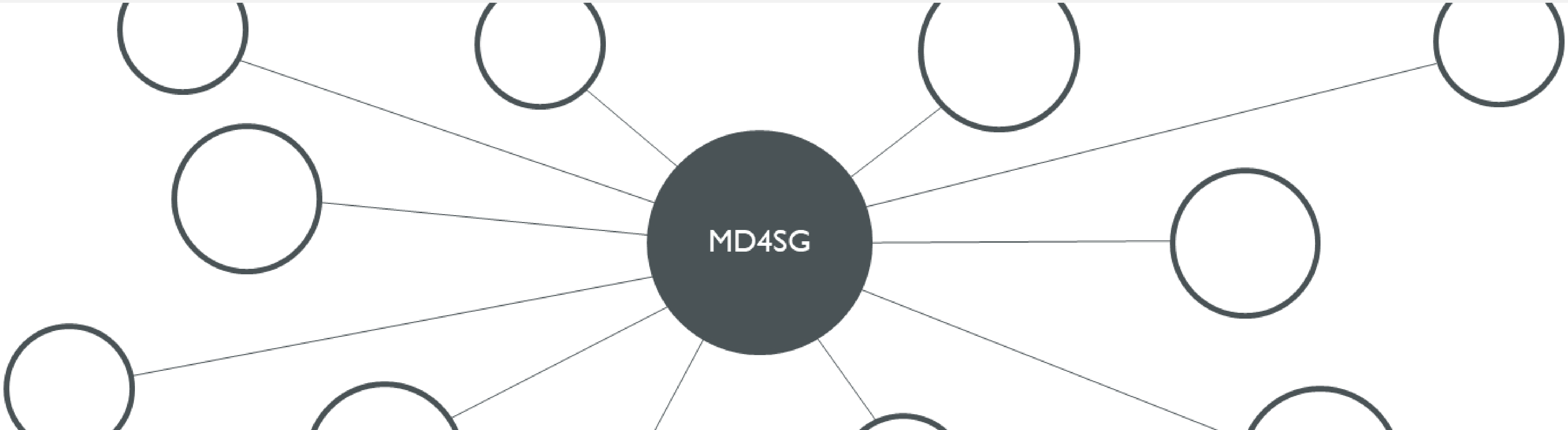
OVERVIEW OF TALK

- An Introduction to Mechanism Design for Social Good (MD4SG)
- Test and Contain
- Current Status and Next Steps
- The Future of MD4SG
- Q&A

WHAT IS MD4SG?

Mechanism Design for Social Good (MD4SG) is a **multi-institutional initiative** using techniques from algorithms, optimization, and mechanism design, along with insights from other disciplines, to **improve access to opportunity** for historically underserved and disadvantaged communities.



WHAT MAKES MD4SG DISTINCTIVE?

- **Multi-disciplinary** collaborations, with focus on algorithms, optimization, and mechanism design, for problem diagnosis and solution design
- **Multi-stakeholder** (and inter-institutional, global, impacted community) engagement for defining and tackling problems
- Common focus on **improving access to opportunity** for historically underserved and disadvantaged communities
- Bridging Research & Practice: An **End-to-End** approach
- Values of Diversity, Equity, and Inclusion

WORKING GROUP COLLABORATIONS

Working groups are the core of MD4SG and a backbone of our community:

- Bring together groups of researchers and practitioners
- Explore an area together: 200+ participants from over 20 countries
- Arrive at a shared research and/implementation agenda/purpose

WORKING GROUP COLLABORATIONS

TEST & CONTAIN

A COLLABORATION BETWEEN

UNIVERSITY OF OXFORD

IPICYT
INSTITUTO POTOSINO DE INVESTIGACIÓN CIENTÍFICA Y TECNOLÓGICA, A.C.

Tecnológico de Monterrey

UASLP
Universidad Autónoma de San Luis Potosí

MAIN PROBLEM

- Accurate and extensive testing of population required to combat Covid-19
- Resources can be extremely limited:
  - Tests
  - Trained personnel
  - Lab time

How do we maximise the benefit of these limited resources?

TESTING OBJECTIVES

- Minimise propagation of virus
  - i.e. prioritise those susceptible or likely to spread
  - Protecting vulnerable segments of the population
- Minimise impact of unecessary self-isolation
  - Essential workers
  - Those without the economic means to self-isolate
  - Easing out of lockdown

GROUP TESTING

- Research has shown that Covid-19 tests are sensitive enough to pool samples together
  - If a single individual is sick, test is positive
  - If all individuals are healthy, test is negative
- Has potential to drastically reduce the number of tests needed to tackle objectives from before
- Our partners at the Vasudevan Laboratory have pioneered a novel methodology to perform group testing while preserving test sensitivity

EXAMPLE: DORFMAN'S 2-STAGE PROTOCOL

- Population of size n, with k infected individuals
- Test on groups of size $\sqrt{n/k}$
- For positive groups, individually test patients in them
- With knowledge of k, requires at most $2\sqrt{nk}$ tests
- Group could be household

BEYOND DORFMAN

What if we don't have enough test for Dorfman?

- Rather than starting with a population and trying to figure out the minimal number of tests required, we start with a testing budget and aim to maximise the benefit of a testing allocation
- If we're ok with not knowing everyone's diagnosis on an individual level, we can reduce the number of tests required
- Surprisingly simple mechanisms can yield improvements

UNIFORM GROUP TESTING

- The simplest way of group testing
- Suppose we have a population of size n
- The testing protocol has two parameters:
  - t: the number of tests allocated to population
  - g: the granularity of tests (i.e. group sizes used)
- Test t disjoint groups of size g

LOW GRANULARITY TESTING

- We assume a testing budget: T
- Population of n individuals
- Belong to C categories
- Each category, C_i has the following characteristics:
  - p_i: baseline probability of infection
  - d_i: connectivity / exposure
  - γ_i : cost of self-isolation
  - n_i : number of individuals in the class
  - s_i : whether the segment is in self-isolation or not

LOW GRANULARITY TESTING

- Consider testing strategies that consist of disjoint uniform group testing strategies for each category
- A feasible testing protocol consists of:
  - t_i: number of tests allocated to C_i
  - g_i: granularity of uniform group testing within C_i
- Constraints:
  - $g_i t_i \leq n_i$
  - $g_i \leq G = 10$
  - $\sum t_i \leq T$

CONTAGION MODEL AND SELF-ISOLATION POLICY

- We assume a single step of contagion
- Initially individuals of C_i are infected with iid probability p_i
- Subsequently, the population is tested according to feasible variable granularity testing strategy
- Self-isolation policy assumptions:
  - If individual is in positive group test, then forced to self-isolate
  - If individual is negative test, or untested, no change in behaviour

OBJECTIVES

- Minimise propagation of virus
  - i.e. prioritise those susceptible or likely to spread
  - In practice, this means large p_i and d_i values
- Minimise impact of unecessary self-isolation
  - i.e. prioritise those with large γ_i values
  - Essential workers
  - Those without the economic means to self-isolate

THE OPTIMISATION PROBLEM

- $r_i = n_i - g_i t_i$, the untested individuals in C_i
- $\beta \in [0,1]$ is a relative weight of each portion of the objective

$$
\begin{aligned}
\min_{g,\ell} \quad & \sum_{i=1}^{C} \ell_i \theta_i(g_i) \\
\text{subject to} \quad & \ell_i \leq \frac{n_i}{g_i} \\
& \sum_{i=1}^{C} \ell_i \leq T \\
& g_i \leq G \\
& g_i, \ell_i \in \mathbb{N}
\end{aligned}
$$

TEST ALLOCATION ALGORITHM

- The objective from before is separable in terms of the allocation of tests to each segment
- If we fix granularities we obtain a mixed integer linear program (MILP)
- We can solve the MILP via a top-down allocation

Algorithm 1 Optimal Segmented Uniform Group Testing

Require:

Granularity Range: $R_G \subseteq [G]^C$

Iterating over Granularities:

$OPT \leftarrow \infty$
for $g \in R_G$ **do**
  $\ell_i \leftarrow 0$ for $i \in [C]$
  Compute σ, an ordering of C_i with respect to increasing $\theta_i(g_i)$ values
  $T_r \leftarrow T$
  $i \leftarrow 1$
  while $T_r > 0$ **do**
    $\ell_{\sigma(i)} \leftarrow \min\{T_r, \left\lfloor \frac{n_{\sigma(i)}}{g_{\sigma(i)}} \right\rfloor\}$
    $T_r \leftarrow T_r - \ell_{\sigma(i)}$
    $i \leftarrow i + 1$
  if $\sum_{i=1}^{C} \ell_i \theta_i(g_i) < OPT$ **then**
    $OPT \leftarrow \sum_{i=1}^{C} \ell_i \theta_i(g_i)$
    $g^*, \ell^* \leftarrow g, \ell$

return g^*, ℓ^*, OPT

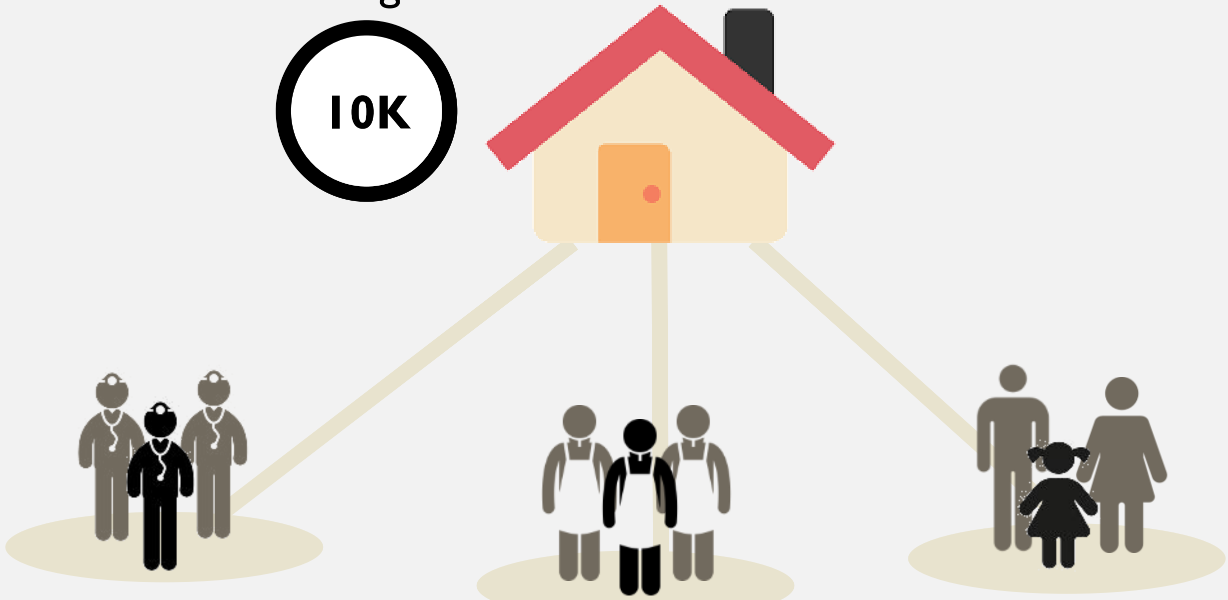
SINGLE VS. MULTIPLE OBJECTIVES

- A key parameter in the model is the cost of self-isolation: γ_i
- Eliciting such parameters may be difficult for a policy-maker
- In this case, we measure a specific testing allocation's performance by multiple metrics rather than the single objective from before:
  - The number of critical COVID cases prevented
  - For each segment, the number of unnecessary self-isolations imposed
- Tradeoffs are inevitable, but we can eliminate testing strategies that are inherently inferior to others (i.e. Pareto dominated)
- In this setting, our framework presents policymakers with families of strategies that exemplify these tradeoffs

POSSIBLE SCENARIO

Village

10K

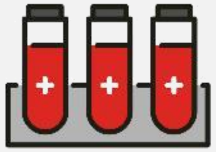


20 Key healthcare workers

480 Regular marketplace workers

9.5K Other townsfolk

500



COVID tests at your disposal

10 people

Group test size limit

What's the best strategy?

CURRENT PRACTICES

- If conscious of health workforce, allocate 20 tests
- For all others, test if individual is already showing symptoms
- Unfortunately these tests are not very informative
- There is an inherent bias in results
- Many cases go un-noticed

UNIFORM GROUP TEST ON WHOLE POPULATION

- Choose a random assignment of 500 groups of size 10 from village
- Place these individuals in group for testing

- Benefits:
  - Covers 50% of the population
  - Can estimate prevalence of virus
- Drawbacks:
  - May unnecessarily self-isolate healthcare workers
  - May not necessarily test an infected marketplace worker

VARIABLE GROUP TESTING

- We consider the case were cost of self-isolation for marketplace workers is high
- Possible testing strategy:
  - 20 tests for individually testing healthcare workers
  - 96 tests of group size 5 (480 individuals tested) for marketplace workers
  - 384 tests of group size 10 for randomly selected groups of townsfolk (3840 individuals tested)

VARIABLE GROUP TESTING

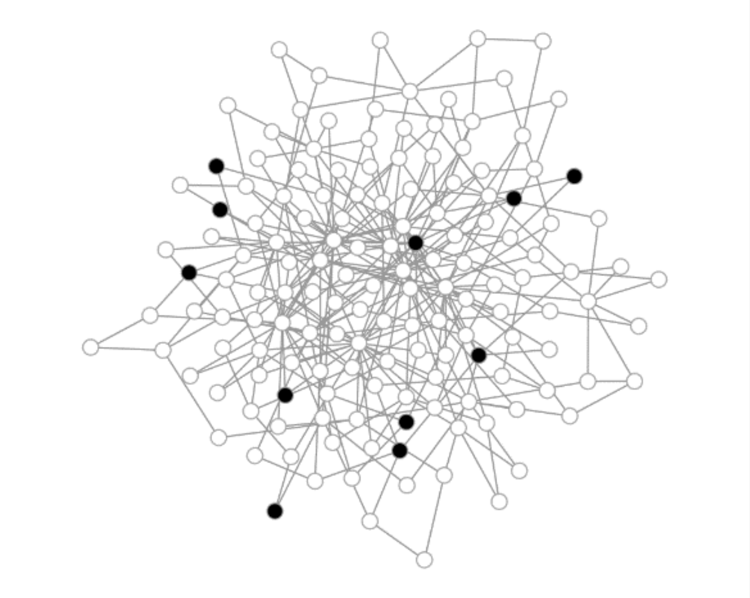
- If cost of self-isolation for marketplace workers is low, can bring the granularity down in their segment while still covering their numbers.
- This frees up tests for the townsfolk
- Possible testing strategy:
  - 20 tests for individually testing healthcare workers
  - 48 tests of group size 10 (480 individuals tested) for marketplace workers
  - 432 tests of group size 10 for randomly selected groups of townsfolk (4320 individuals tested)

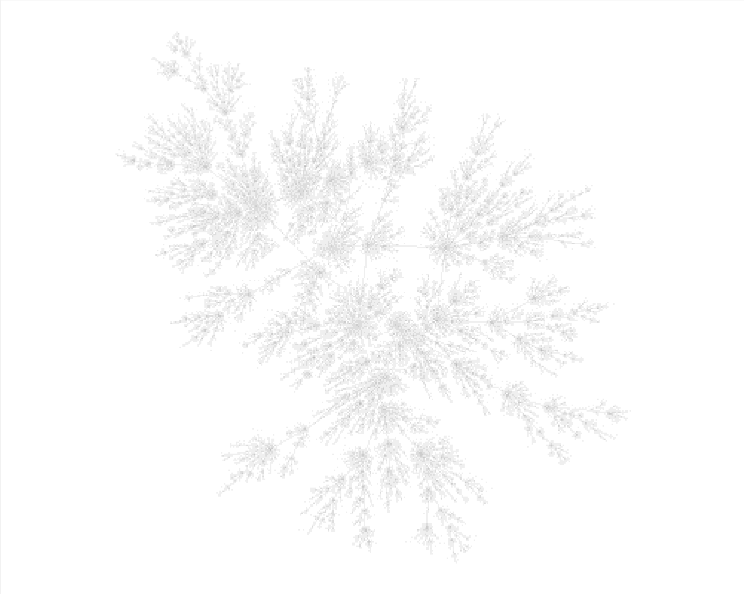
BREAKING THE GROUP TESTING LIMIT

- Individuals with highly correlated infection rates do not need to be tested separately
- Household members fall in this category, and a single test from an individual in the household should suffice to determine whether all or none are infected
- If the household is the basic unit, pooled tests aggregate over households
- In our village example, if the average household is of 3 members, then 317 pooled household tests suffice to cover entire townsfolk segment of population

SIMULATION RESULTS

- Ran a network SIR model over a heterogeneous population



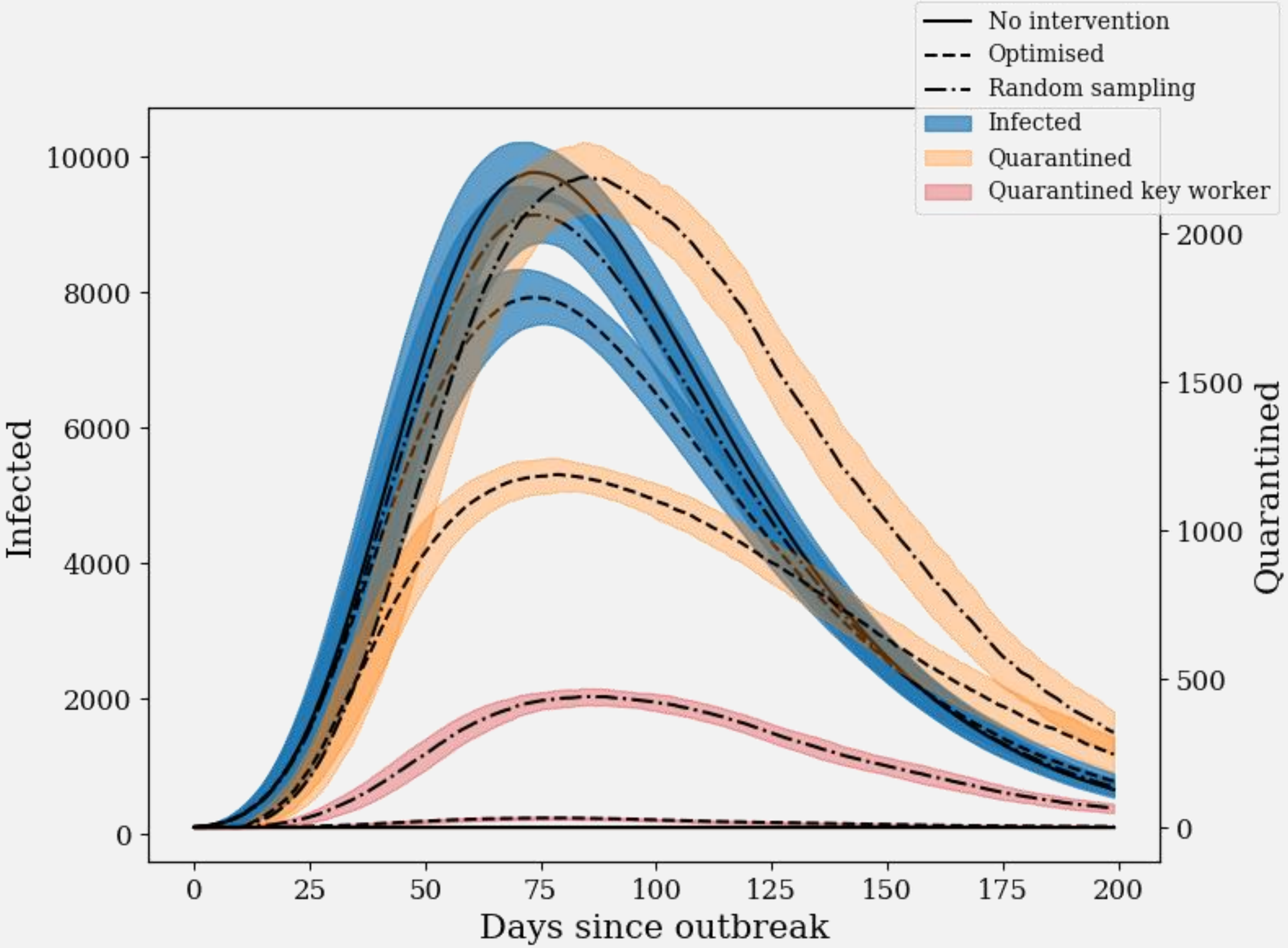


SIMULATION RESULTS

- Ran a network SIR model over a heterogeneous population
- Key parameters:
  - 100,000 individuals in population
  - Baseline infection of 0.1%
  - 20% key workers
  - 16 tests per day
  - 200 days of infection

SIMULATION RESULTS

- We compared the following testing strategies:
  - Baseline (i.e. testing those showing severe symptoms only)
  - Testing groups of size 10 at random
  - Segmented uniform testing:
    - All tests focused on highest connectivity segment
    - Key workers are tested at granularity 1
    - Others are tested at granularity 10
- Same containment policy used throughout



No intervention
Optimised
Random sampling
Infected
Quarantined
Quarantined key worker
Infected
Quarantined
Days since outbreak
0
2000
4000
6000
8000
10000
0
500
1000
1500
2000
0
25
50
75
100
125
150
175
200

SIMULATION RESULTS

- Total number of infected individuals at any given day at most 10% of population
- Random sampling reduces the peak by $(6.5 \pm 6)\%$
- Optimised testing reduces the peak by $(19 \pm 5.5)\%$
- Optimised testing also results in $(45 \pm 3.8)\%$ reduction in number of individuals self-isolating during the peak
- Quarantined key workers at the peak reduced by $(93 \pm 1.2)\%$

EXITING LOCKDOWN

- Up to now we have focused on a scenario where a population is not in lockdown
- In that setting, testing can be interpreted as "finding the infected"
- When a population is in lockdown, the objective is dual to this
- We must instead focus on "finding those healthy"
- Group testing once again provides non-trivial optimizations with respect to this objective

A TOY EXAMPLE

Employee Type	Quantity	Essential	Baseline Infection Probability
Owner	1	1	N/A
Managers	4	2	7%
Technicians	10	2	10%
Assistants	5	0	.5%

Group sizes of at most 15, and a Budget of 6 tests

What is the best strategy?

FINDING HEALTHY INDIVIDUALS

- Suppose that there are n populations segments
- Each has a probability of infection (health) given by p_i (q_i)
- We encode a group test of this population with an n-vector
  - $\vec{a}$, where a_i is the number of individuals in segment i
  - Clearly sum $a_i \leq 10$
- We let H(a) be the expected number of healthy individuals for this group test
- $H(\vec{a}) = (\sum_{i=1}^{n} a_i)\left(\prod_{i=1}^{n} q_i^{a_i}\right)$

FINDING HEALTHY INDIVIDUALS

Employee Type	Quantity	Essential	Baseline Infection Probability
Owner	1	1	N/A
Managers	4	2	7%
Technicians	10	2	10%
Assistants	5	0	.5%

- Test all essential regularly, this leaves one test
- All in one group provides 5.44 healthy individuals in expectation
- 2 Managers, 3 technicians and 5 assistants provides 6.15 healthy individuals in expectation
- Over two testing periods, this is one more person on average!

POTENTIAL EXTENSIONS

- Hybrid optimization
- Staggered lockdown, irrespective of group characteristics
- Bayesian analysis of biomarker data

CURRENT STATUS

- Vasudevan group testing protocol has been validated at IPICYT
- Data collection pipeline:
  - Centinela de la Salud
  - ITESM student information
- Prototype for ITESM “Regreso Consciente” is imminent
- Nascent collaboration with UASLP medical school
  - Simple objective: opening primary school education in disadvantaged municipalities in SLP
  - Senior government official involvement
  - In MD4SG spirit, the most important aspect of the project is engaging directly with the community [parents].

MD4SG EXEMPLIFIED

- Perfect example of how MD4SG works in motion
- Test and Contain has been a collaboration between:
  - Researchers at the University of Oxford and Mexico (IPICYT, ITESM)
  - Policymakers from the state of San Luis Potosi, Mexico
  - Academic administrators at ITESM
- Funded by ACM Special Interest group on Economics and Computation (SIGEcom), and Facebook through "Global Challenges in Economics and Computation"

A GLOBAL ORGANISATION

Diverse and experienced leadership

Rediet Abebe

Berkeley
UNIVERSITY OF CALIFORNIA

Irene Lo

Stanford
University

Ana Andreea-Stoica

COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

Wanyi Li

Stanford
University

Francisco Marmolejo

UNIVERSITY OF
OXFORD

2,000+

Participants

9

Working Groups

Workshops, colloquiums, conference & more

THANK YOU!

[WWW.TESTANDCONTAIN.ORG](http://www.testandcontain.org)

SPECIAL THANKS:

EDWIN LOCK
JAKOB JONNERBY
HECTOR GUZMAN
SALVADOR RUIZ-CORREA
RUBEN LOPEZ-REVILLA

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