Unified Screening for Multiple Diseases

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https://github.com/ynarter/UniScreen

Motivation & Problem

- **Current state:** Screening programs are disease-specific.
- **Limitation:** Ignores competing risks — interactions between disease outcomes.
- **Goal:** Unified screening optimizing outcomes under constraints.

Contributions

- Formalize **"Unified Screening"** as an optimization problem
- Model competing risks and resource constraints
- Prove structural properties of optimal referral policies
- Validate through in-silico experiments
- Show gains over independent screening

Problem Formulation

- **Patient model:** Risk vector $X = [X_1, \ldots, X_N]^T \in [0,1]^N$, Disease state $\Theta_n \in \{0,1\}, n \in [N]$, Screening target $Y_{\mathrm{n}}(t)$
- **Actions:** Screening action $\delta(t)$, Diagnostic action $\hat{\theta}_n(t)$
- **Objective:** Maximize expected survival time T^* up to T_0 with budget and diagnostic error constraints

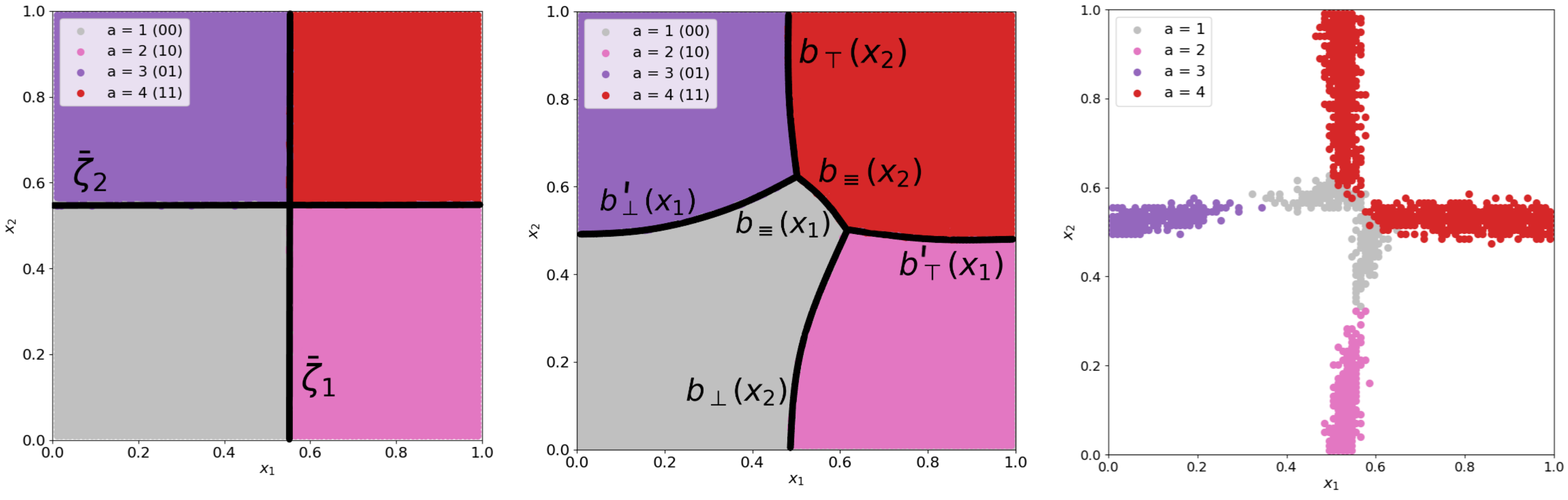
Referral Problem

- Given existing policies per disease, learn referral decision $\rho(X)$.

- Advantages:
  - Feasible in clinical workflows.
  - Optimal combinations of existing policies.
  - Lower bound on full joint optimization.

Theoretical Results

- Optimal decision boundaries are not static thresholds.
- They are **curves** — depend on both disease risks (X_1, X_2).
- **Key property:** Screening threshold for Disease 1 depends on Disease 2 risk and vice versa.

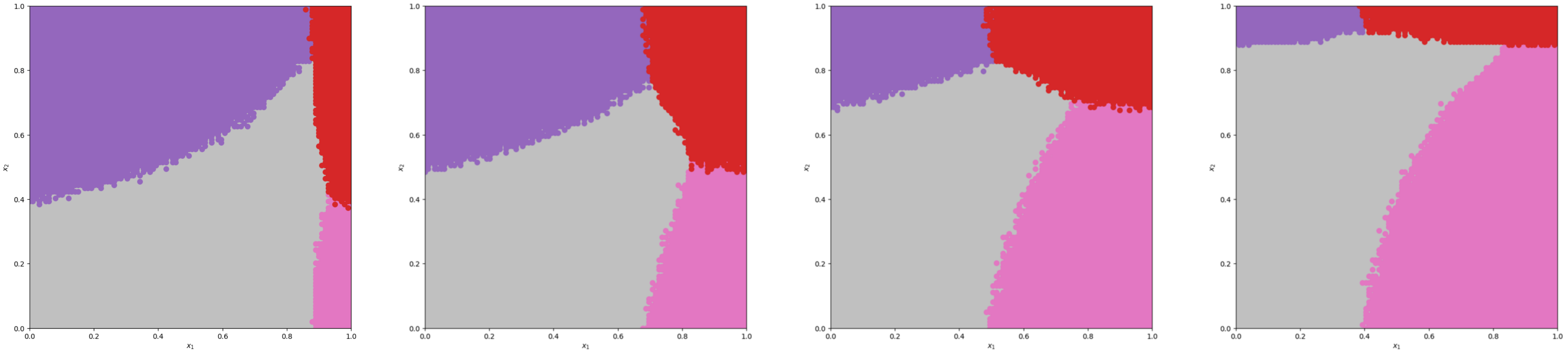


(a) (b) (c)

Figure 1: Optimal referral policy under unified screening (a) vs independent screening (b). In the unified model, the activation threshold for each disease adapts based on the risk of the other disease, resulting in curved, risk-dependent decision boundaries. The difference plot (c) highlights regions where the unified policy activates screening while the independent model does not, and vice versa.

Experimental Setup

- $N = 2$ diseases, age ≥ 50.
- Risks $X_1, X_2 \sim Beta(\alpha, \beta)$
- Adverse event times $T_n \sim N(\mu_n, \sigma^2)$
- Screening: periodic every 1 year.
- Monte Carlo: $M = 200$ for 10k risk vectors.



(a) (b) (c) (d)

Figure 2: Varying the screening costs for the diseases with other parameters fixed, (a) $c_1 = 6, c_2 = 1$, b) $c_1 = 2$, $c_2 = 1$, (c) $c_1 = 1$, $c_2 = 2$, (d) $c_1 = 1$, $c_2 = 6$. As the cost of screening for one disease increases, the model shifts its screening priorities to favor lower-cost, higher-yield screenings, demonstrating efficient budget allocation.

Results: Unified vs Independent Screening

- Unified Screening outperforms with:
  - **Higher survival times**: statistically significant improvement in expected survival time.
  - More joint screenings → **better resource use**.
  - Thresholds **adapt to risk interplay** → non-linear boundaries.

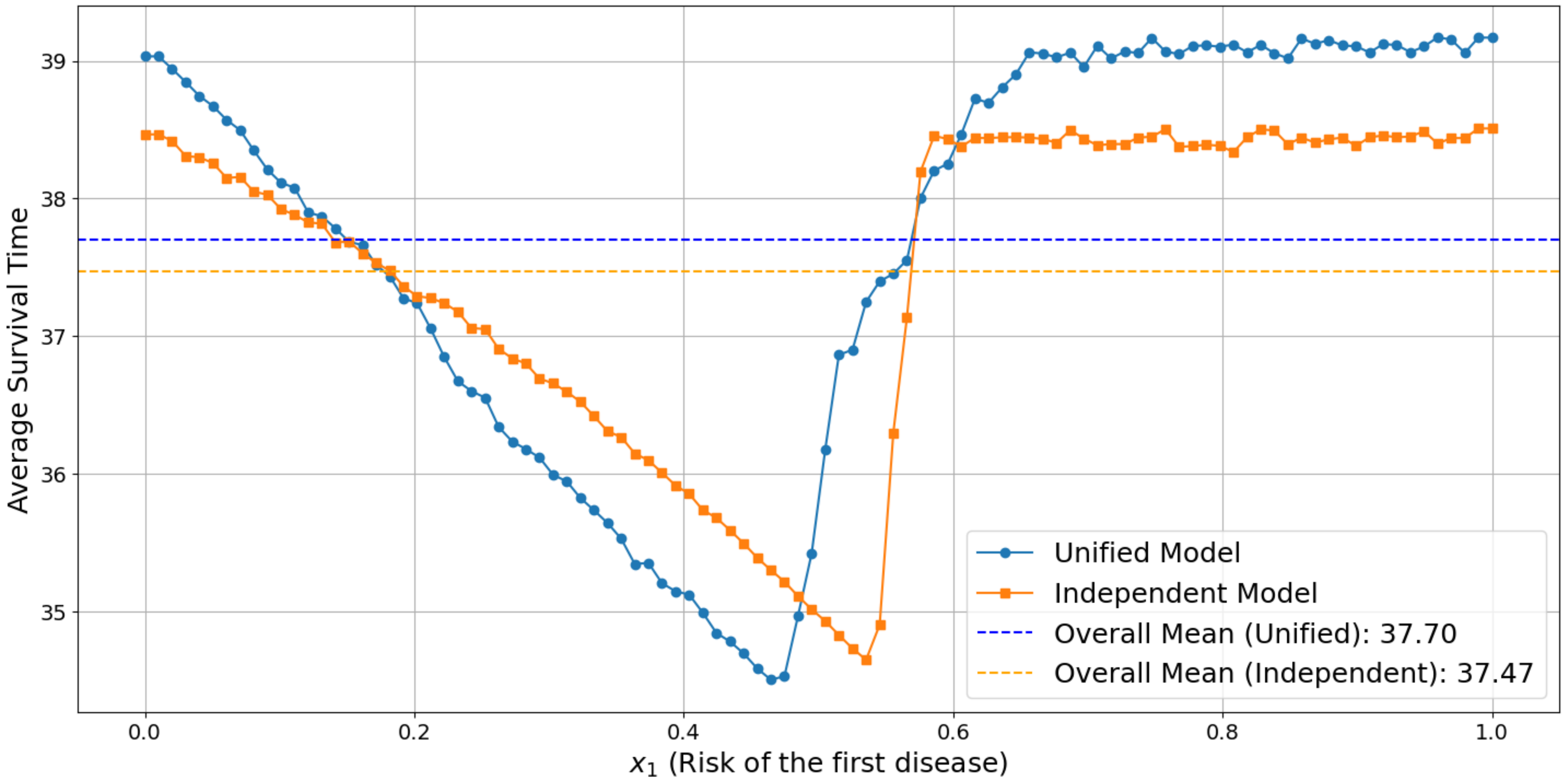
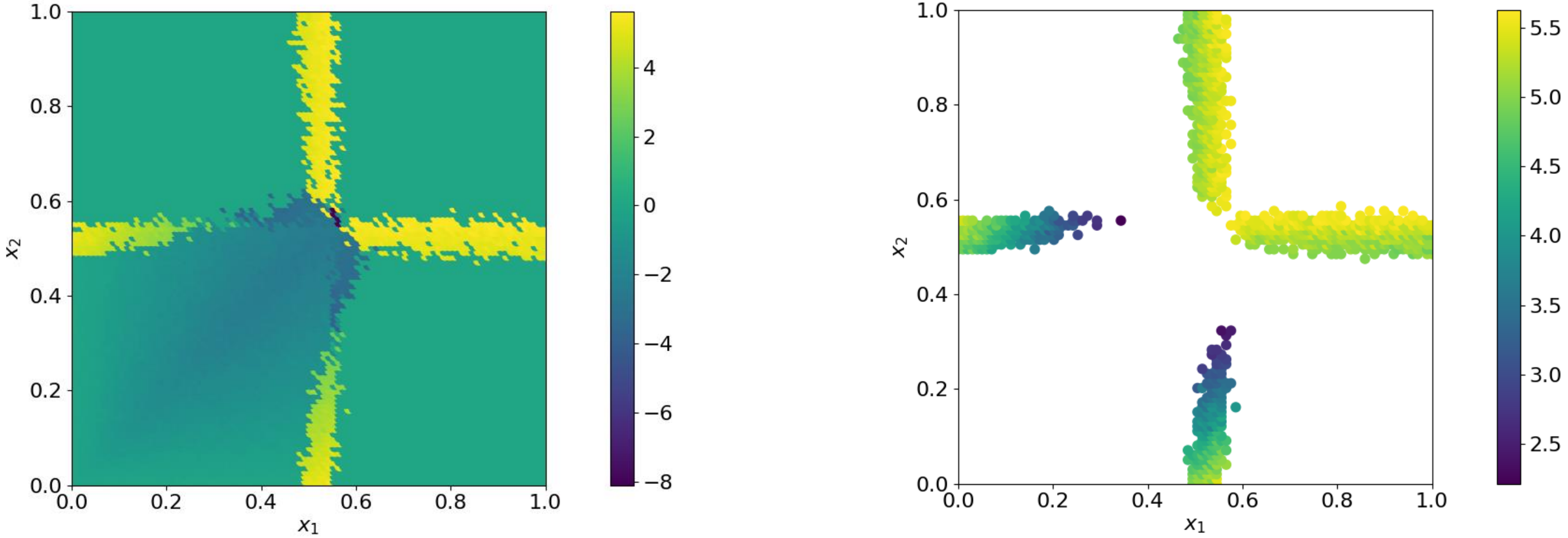


Figure 3: Average survival times (in years excess of 50) with respect to x_1 (the first disease risk) for both the unified and independent screening programs computed by taking the mean survival times over all x_2 values (the second disease risk). The unified screening model yields higher survival times across a broad range of patient risk profiles, with an overall gain of statistically significant improvement in expected survival time.



(a) (b)

Figure 4: (a) Difference in expected survival times (Unified − Independent) across the 2D risk space, (b) Regions of the risk space where unified screening outperforms independent screening. The unified model delivers the greatest gains in regions where risks are asymmetric — effectively prioritizing patients who benefit most from tailored joint screening decisions.

Practical Impact & Future Work

- **Impact:**
  - **Better survival outcomes** with **the same budget**.
  - Efficient use of screening resources.
  - Scalable to clinical settings.

- **Future work:**
  - $N > 2$ diseases.
  - Incorporate harms (overdiagnosis).
  - Clinical validation.

Summary

- First framework unifying:
  - **Competing risks**
  - **Resource constraints**
  - **Multiple diseases**

- Unified Screening: promising for healthcare optimization.