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The University of Texas at Austin

Modeling and Countering Misinformation in Adversarial Information Ecosystems

Arash Amini, Yigit Ege Bayiz, and Ufuk Topcu

AFOSR Center of Excellence in Assured Autonomy in Contested Environments

Information Enviroment

Defense for Special Operations and Low-Intensity Conflict, stated that adversarial use of *disinformation*, *misinformation*, and *propaganda* poses one of today's *greatest challenges* to the United States.

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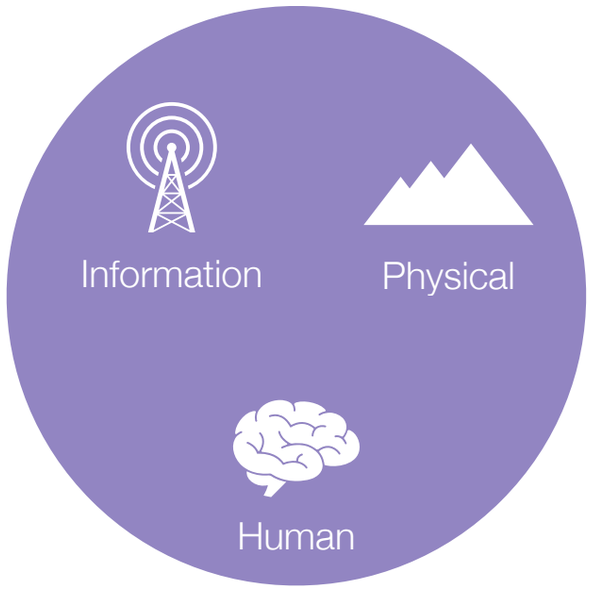

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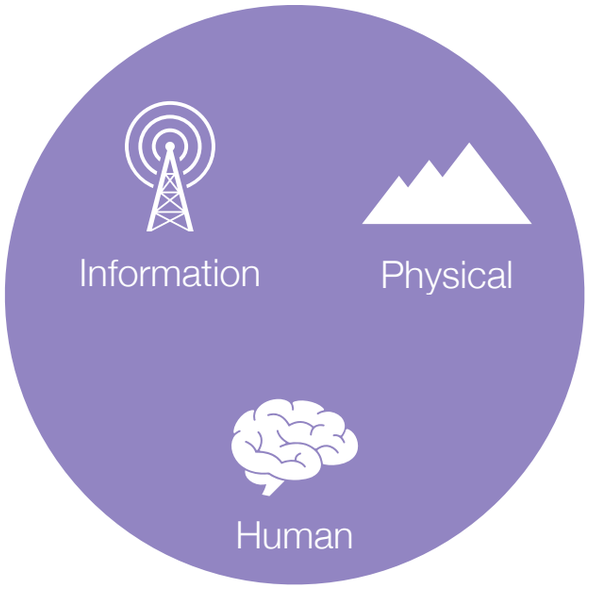

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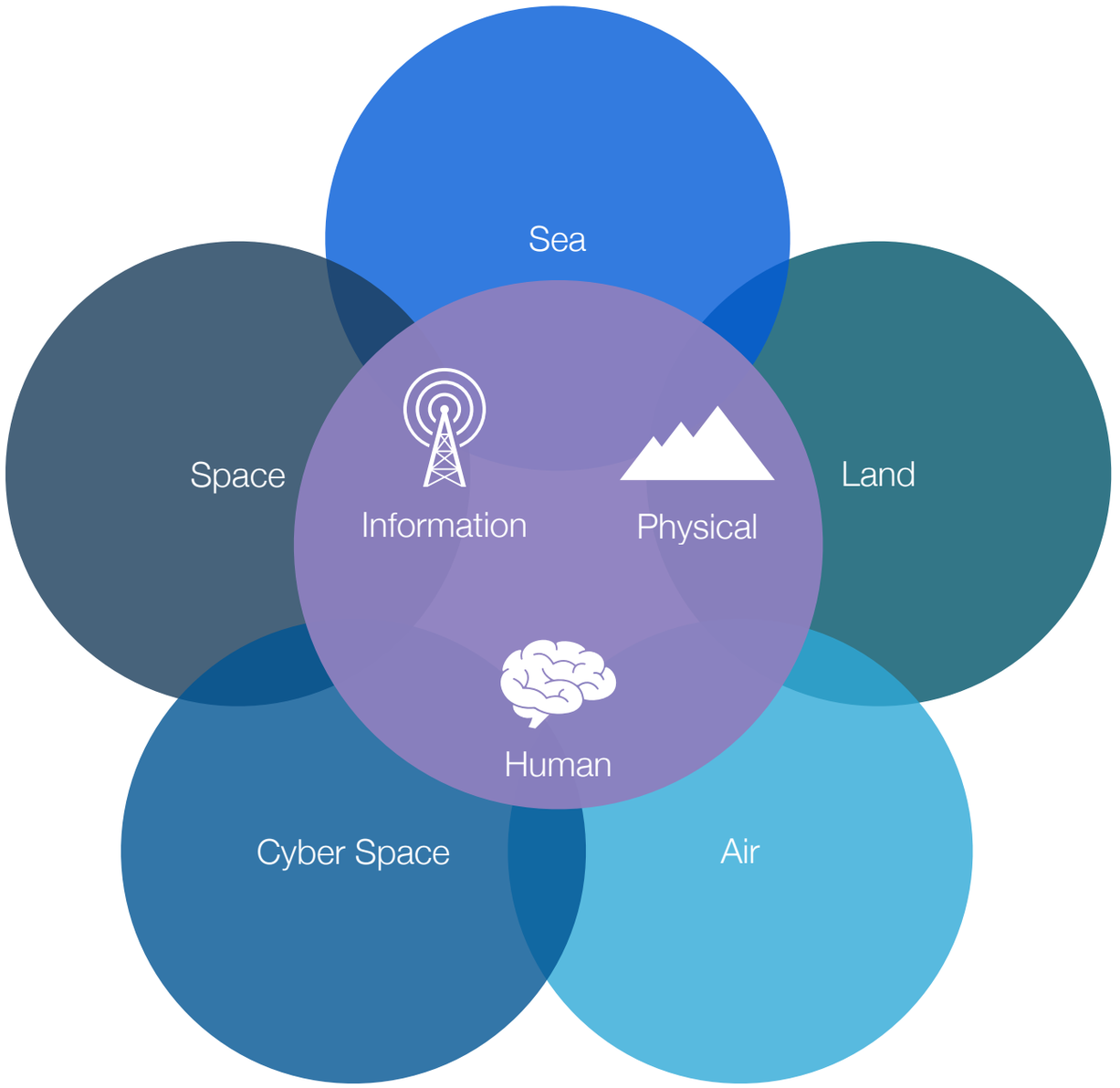

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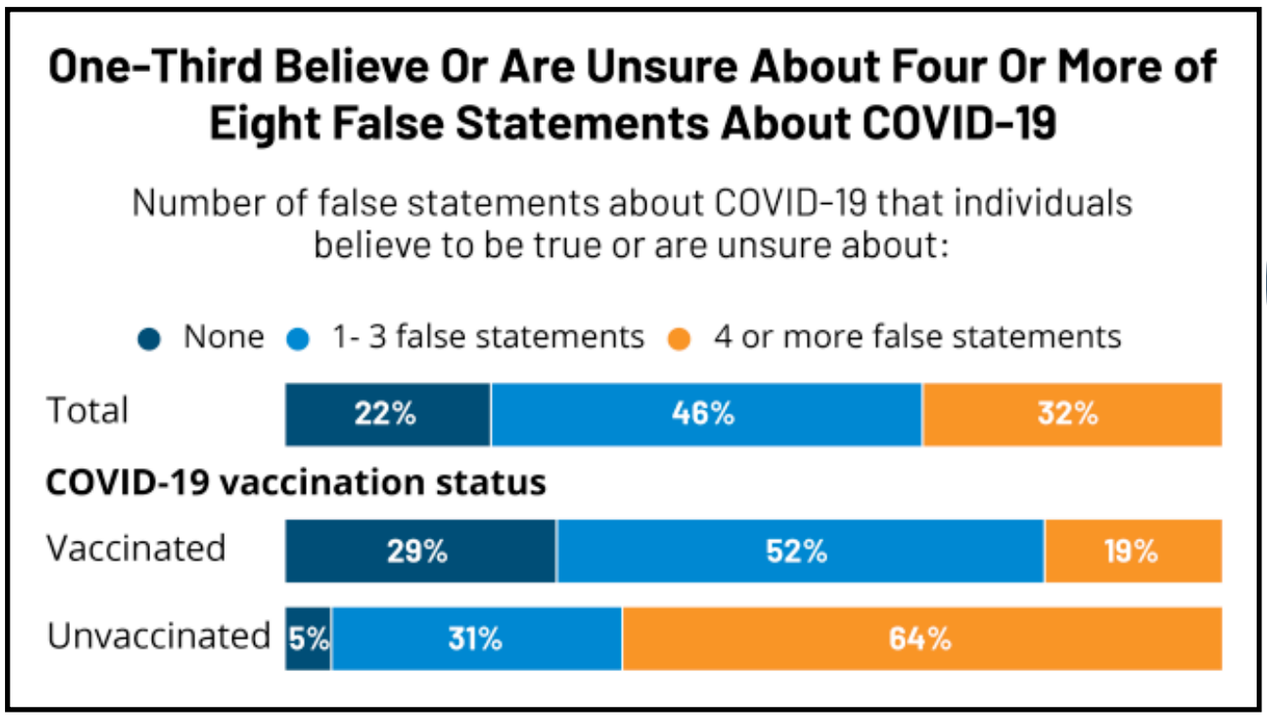
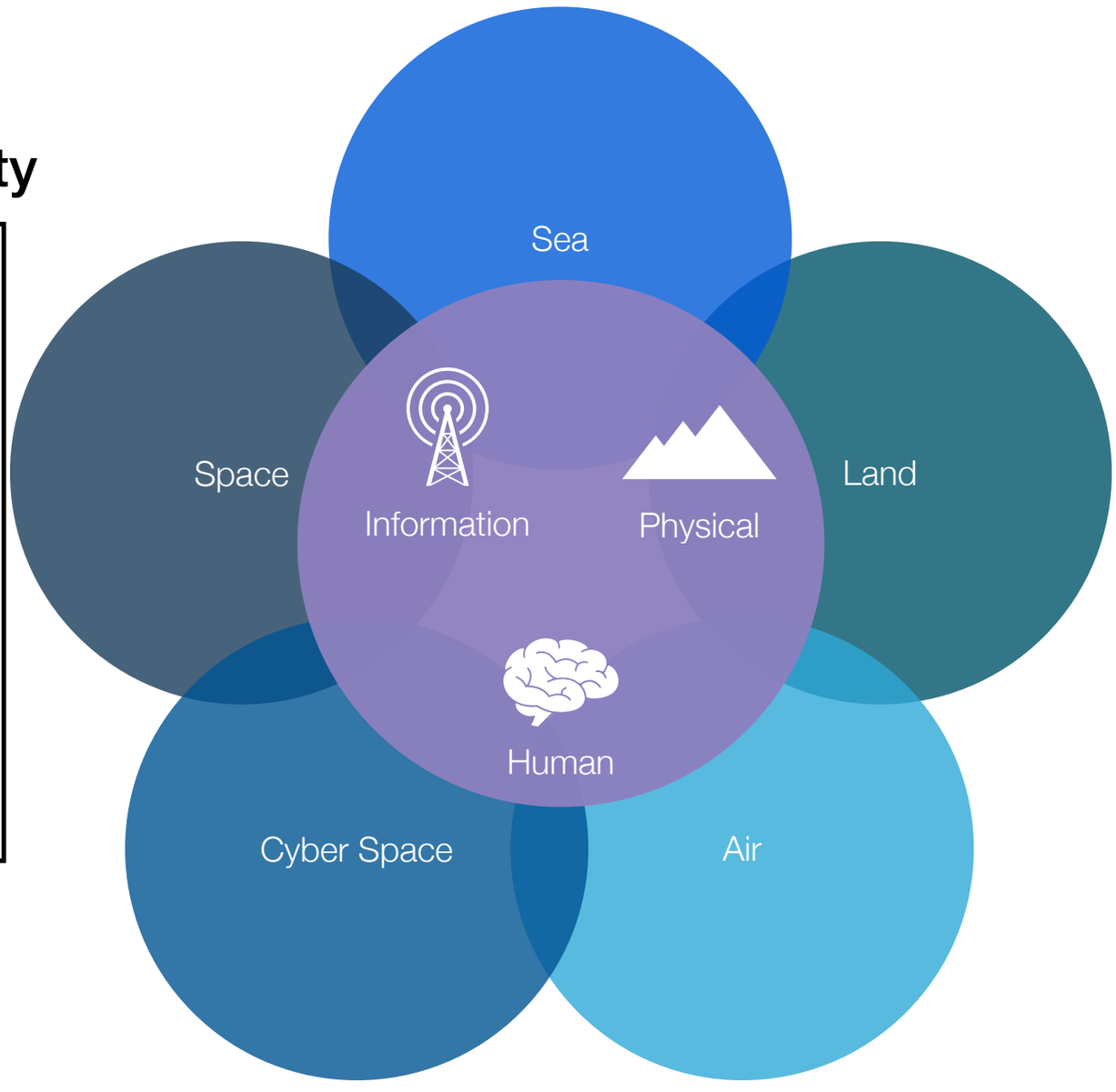
A real threat that goes beyond national security





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How Disinformation Works

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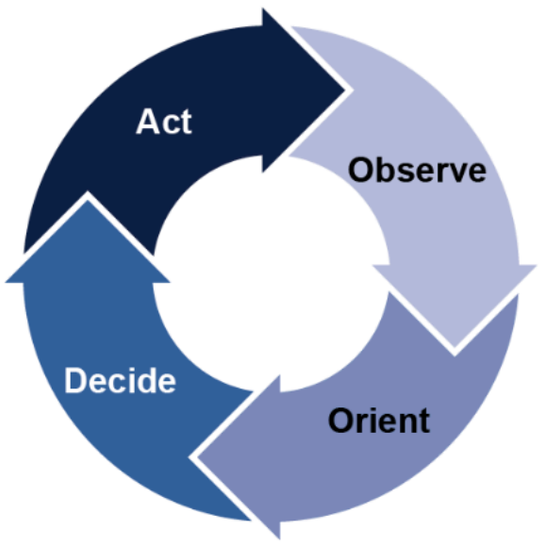

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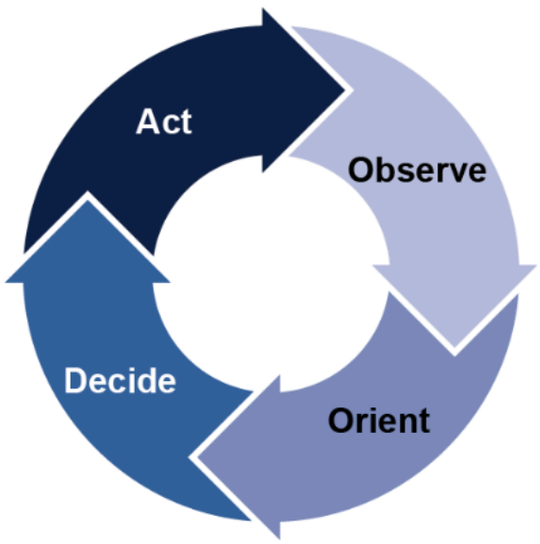

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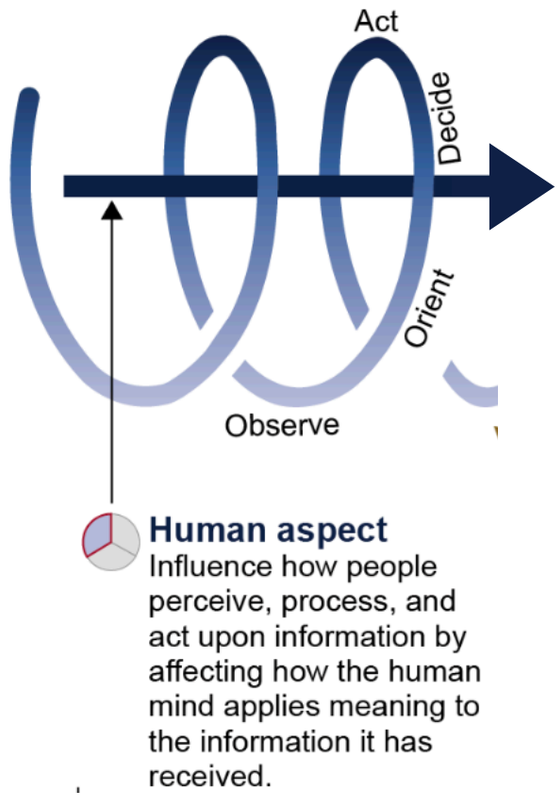

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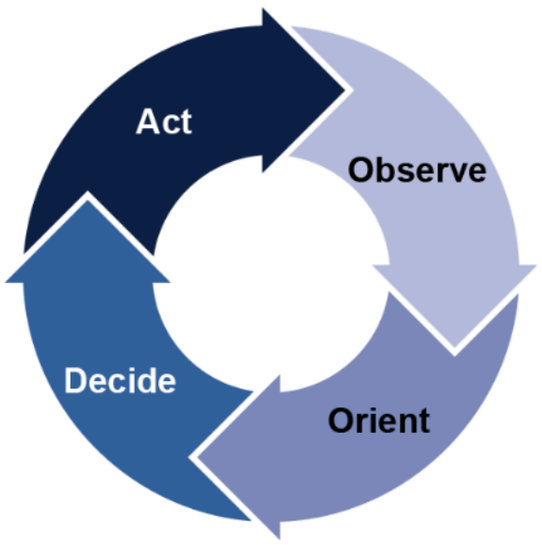

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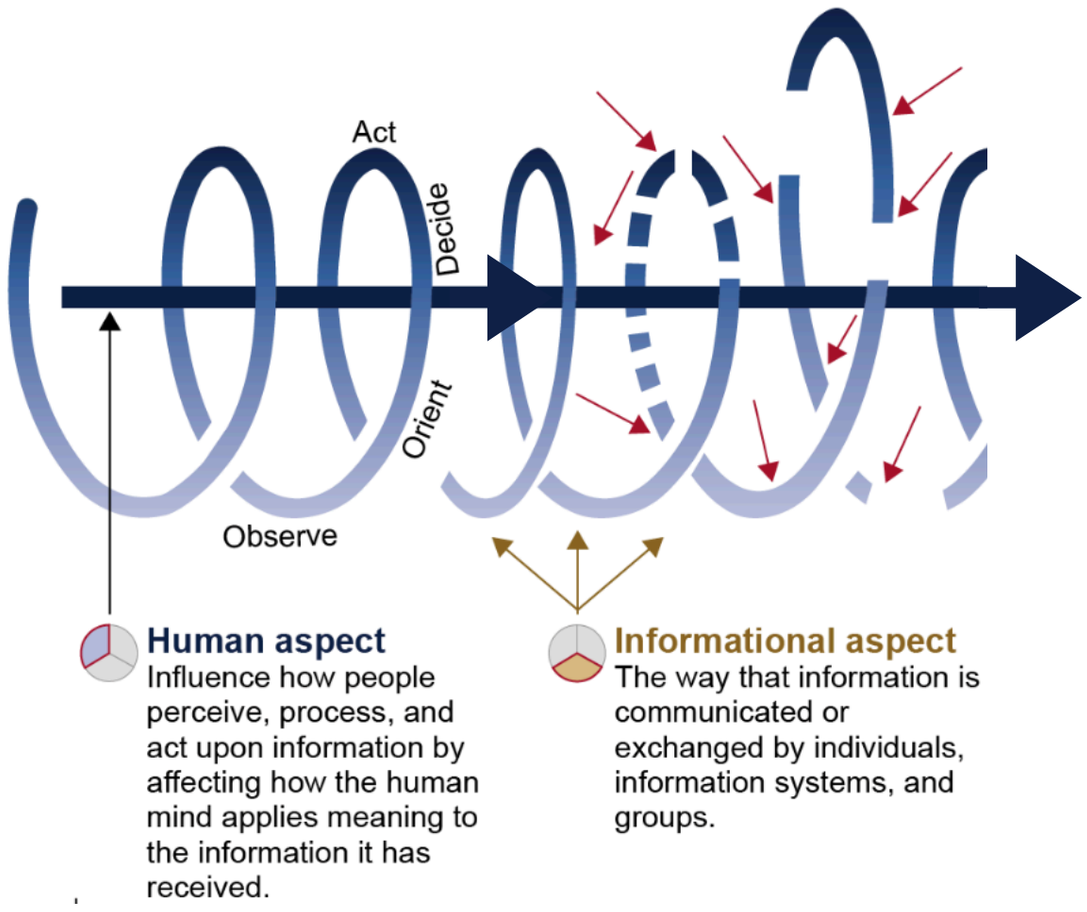

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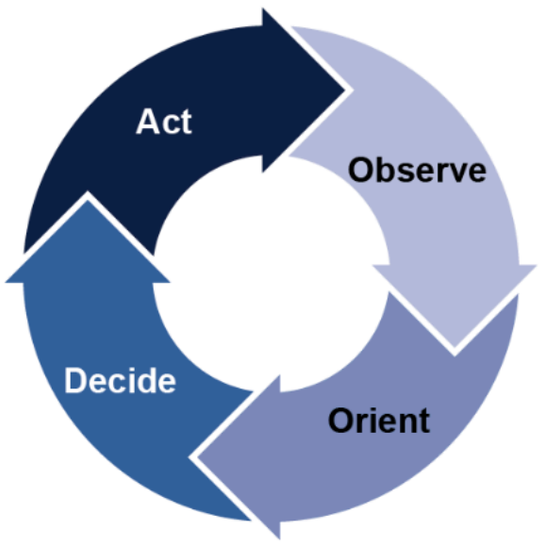

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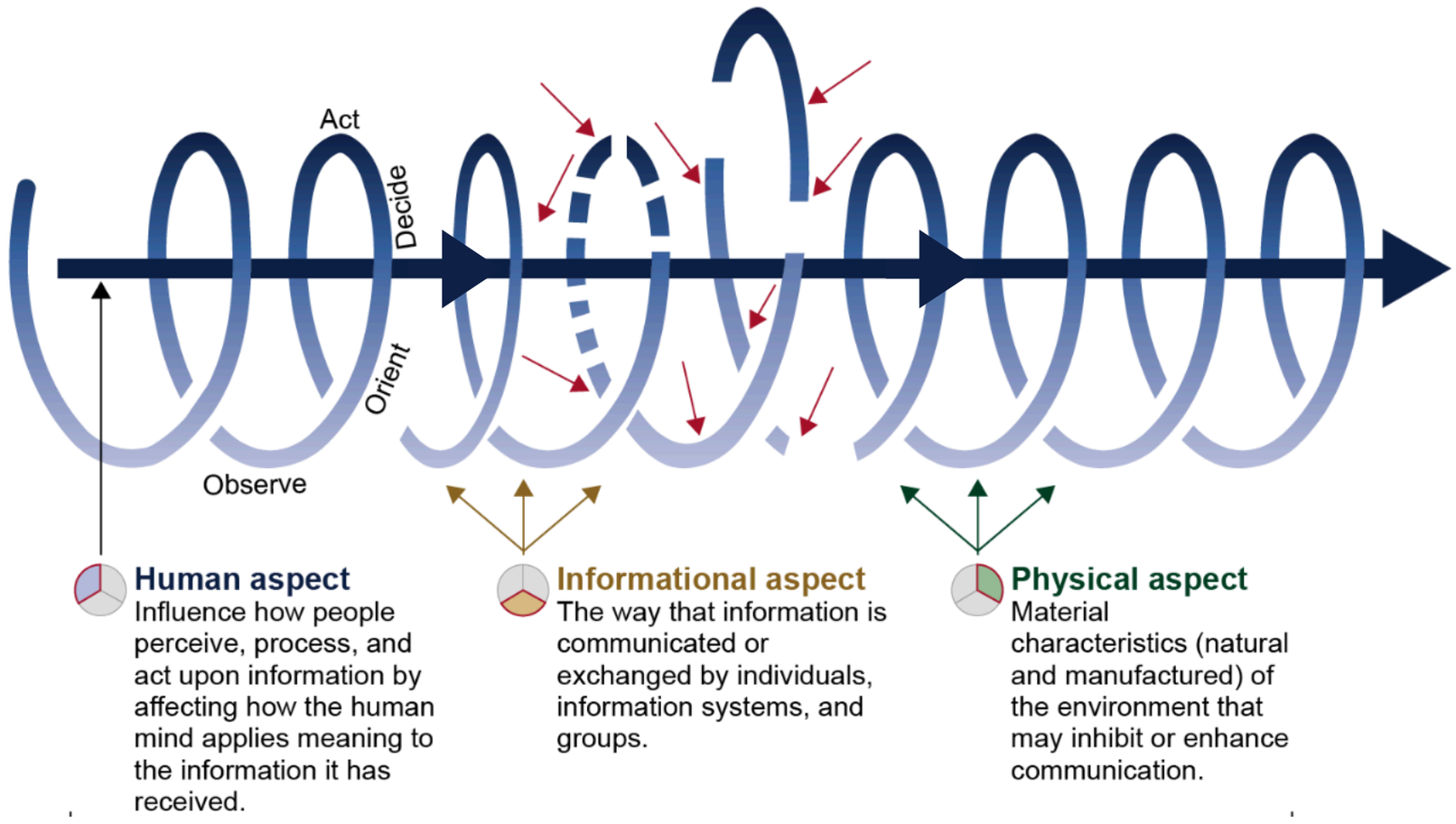

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Definition of Disinformation

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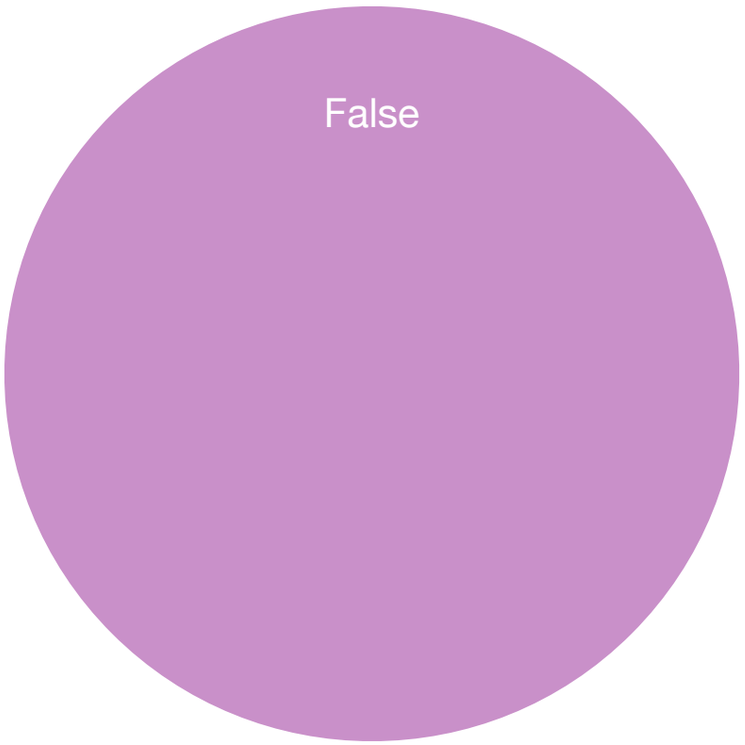

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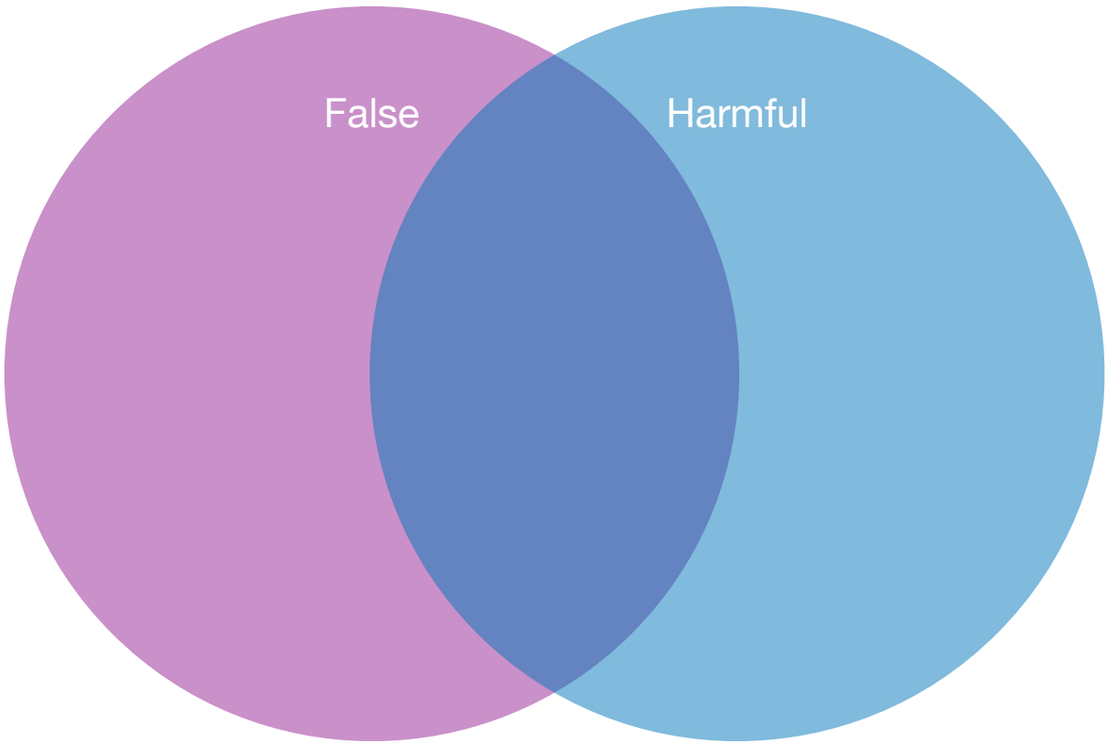

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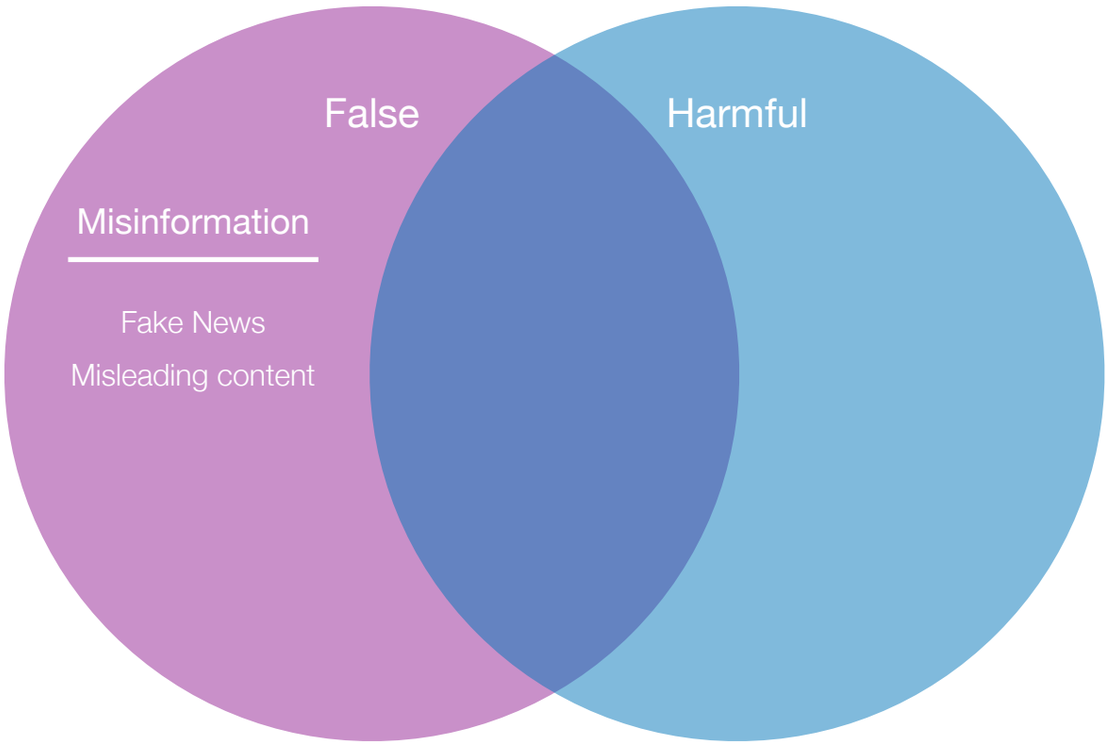

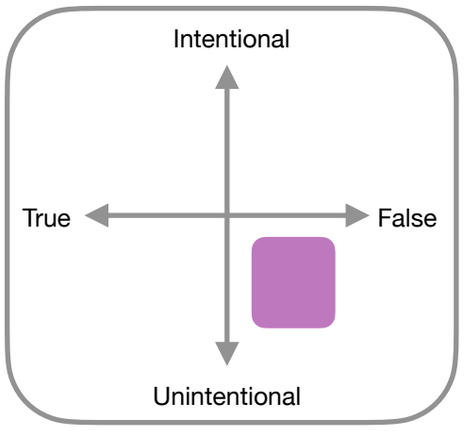

Misinformation

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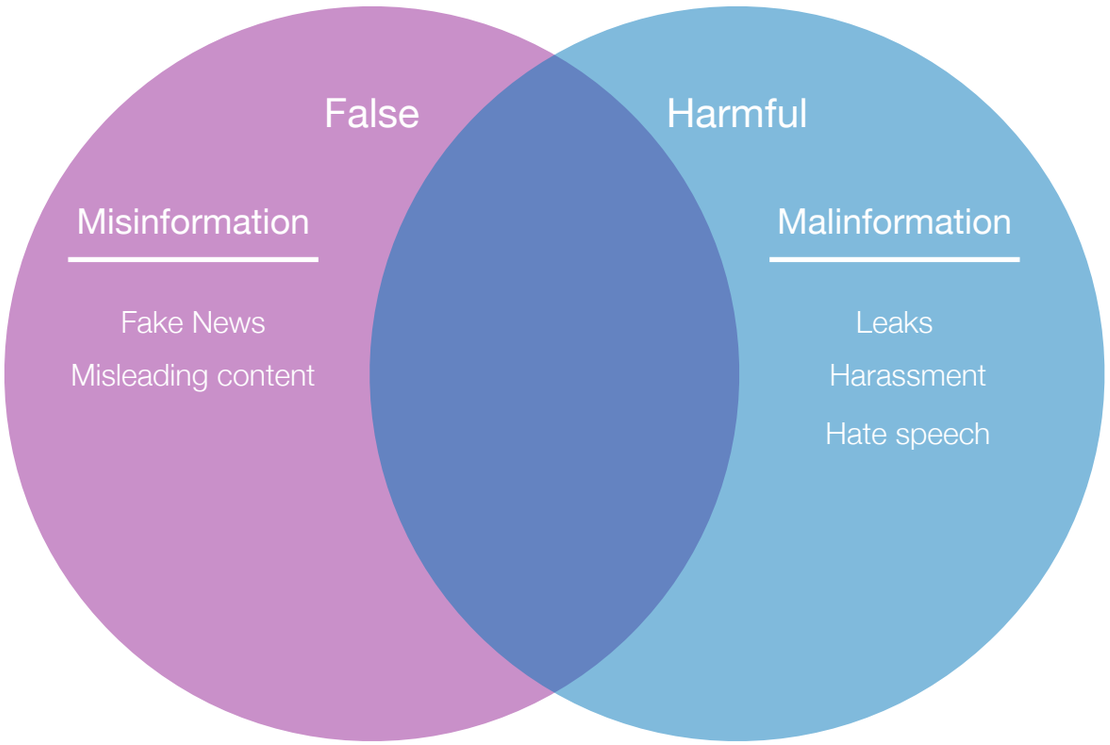

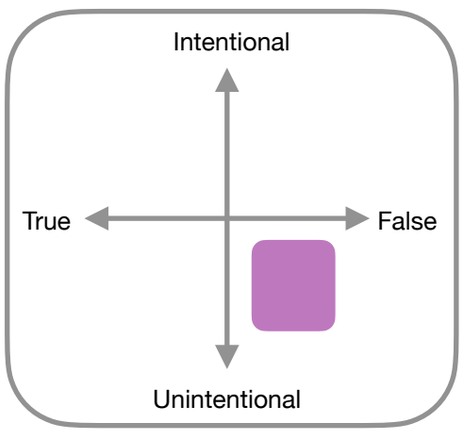

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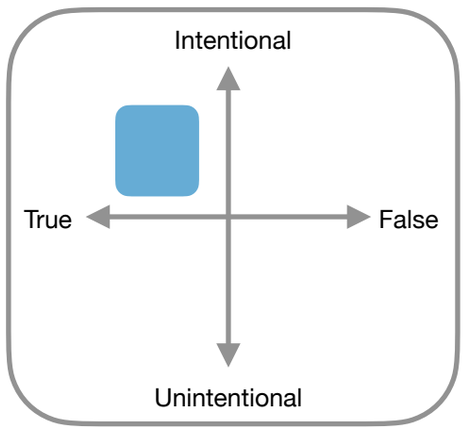

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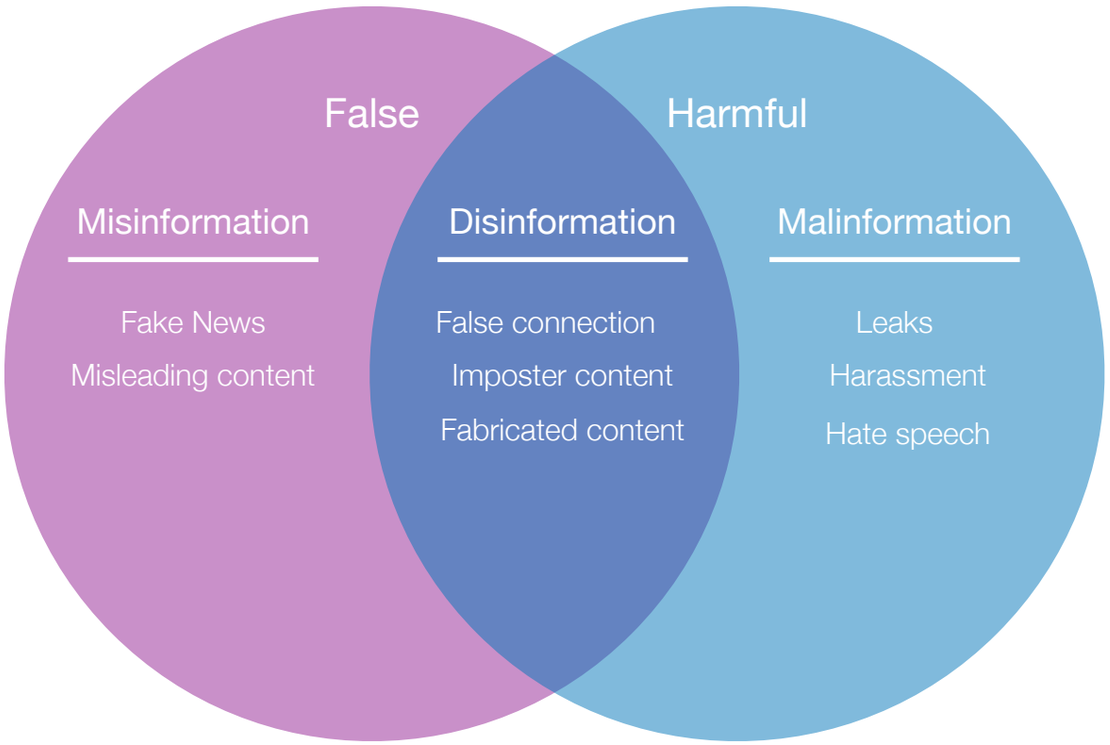

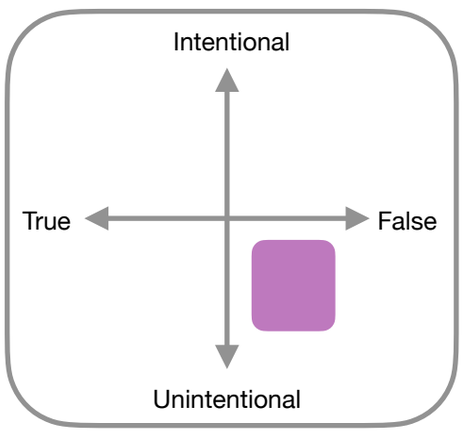

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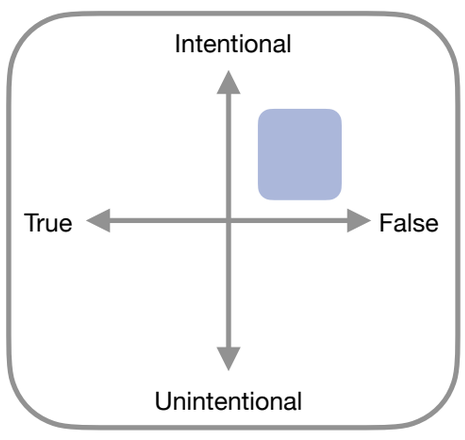

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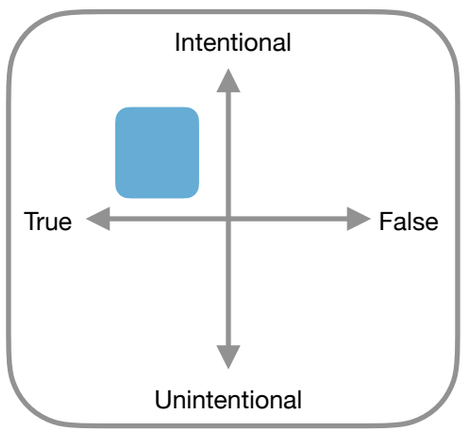

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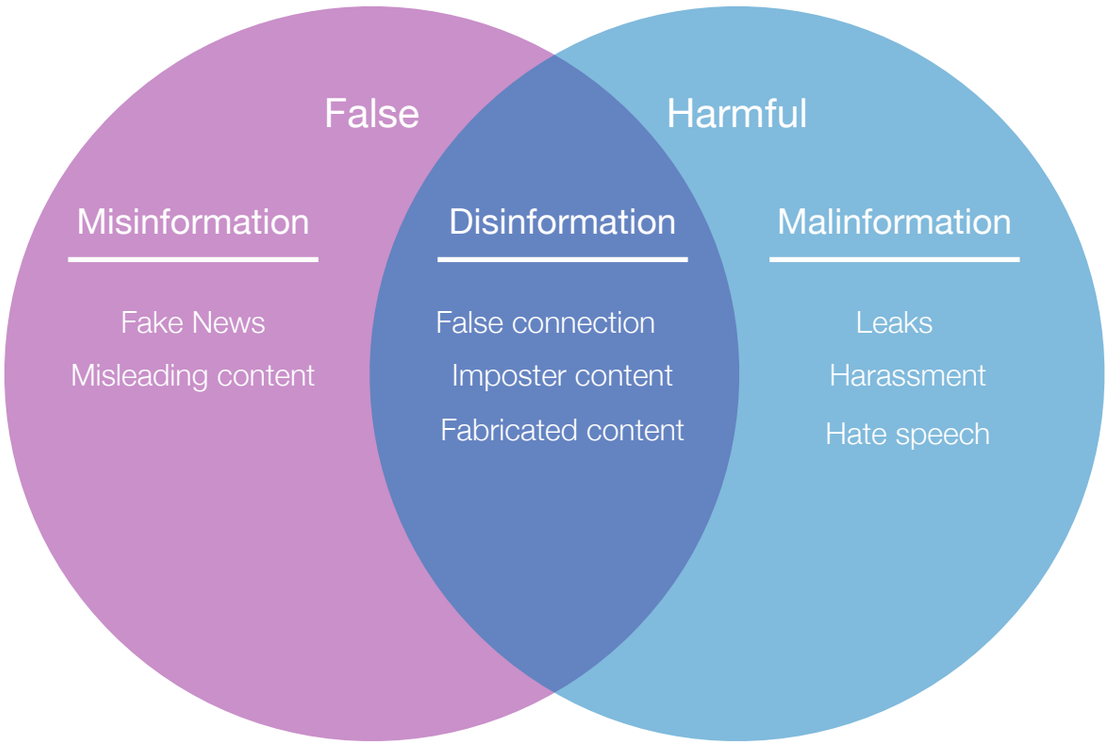

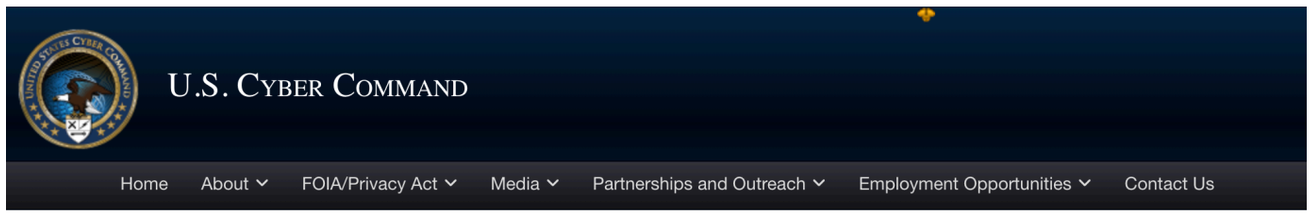

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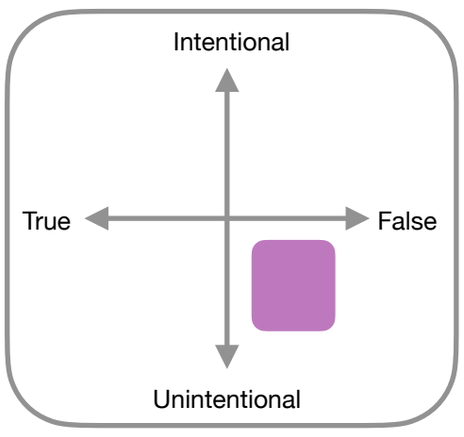

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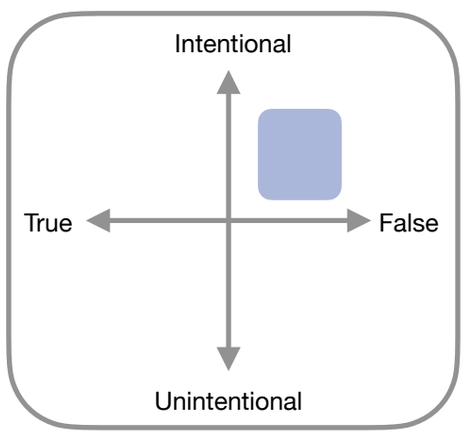

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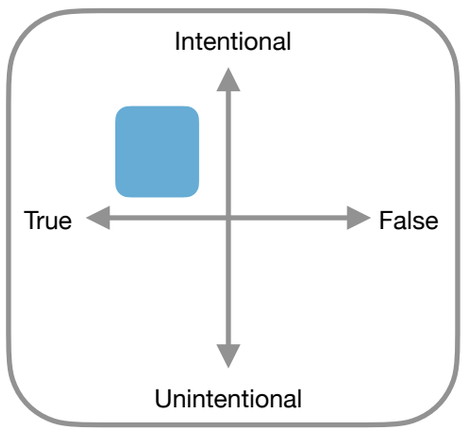

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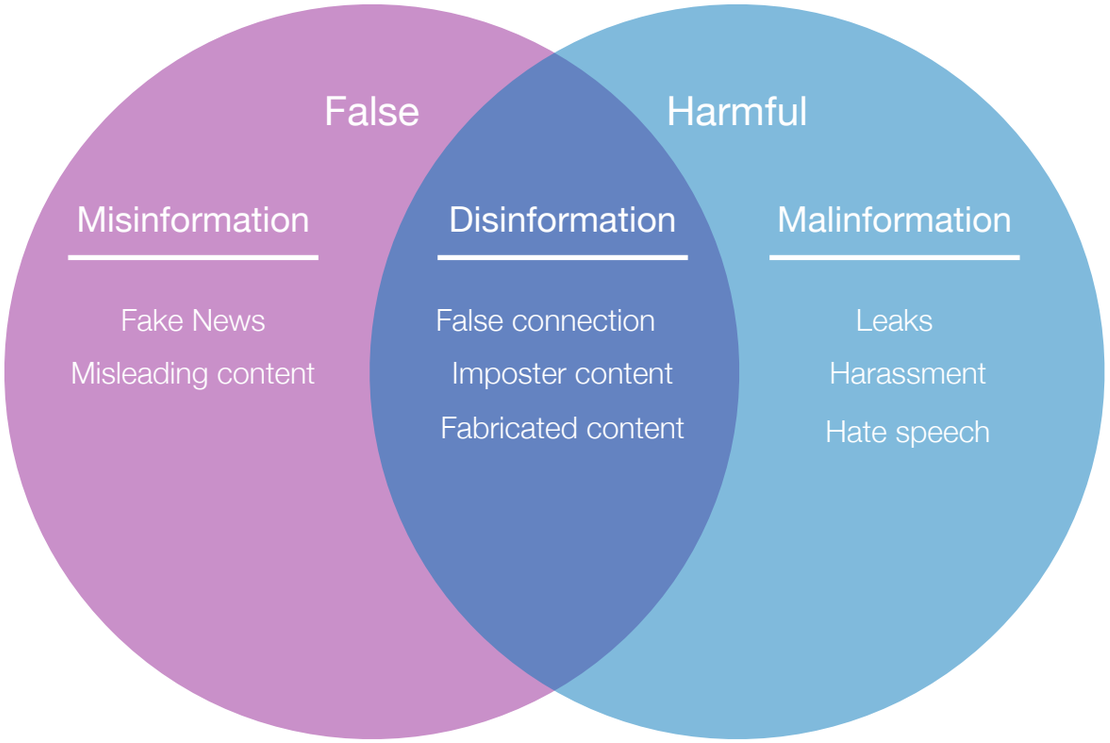

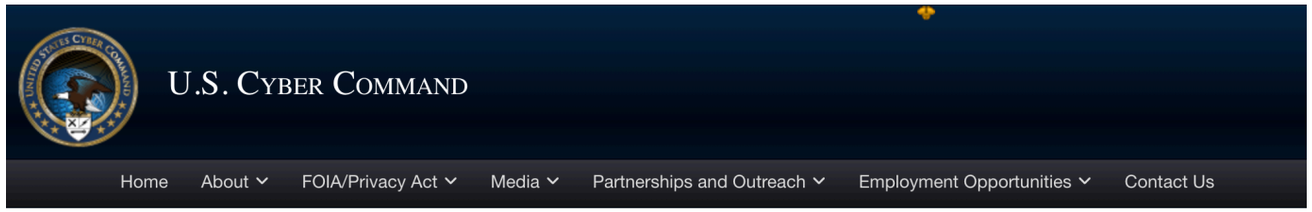

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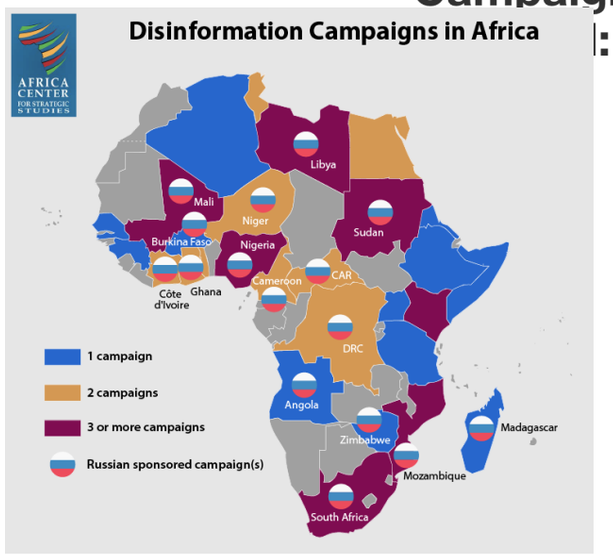

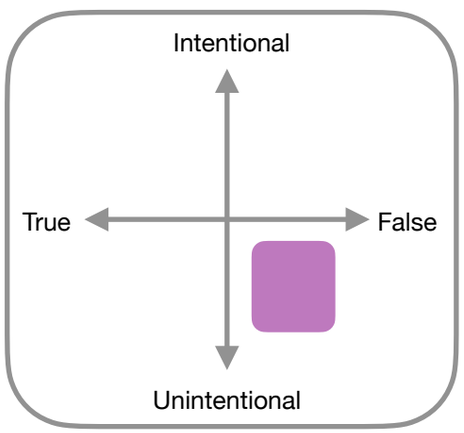

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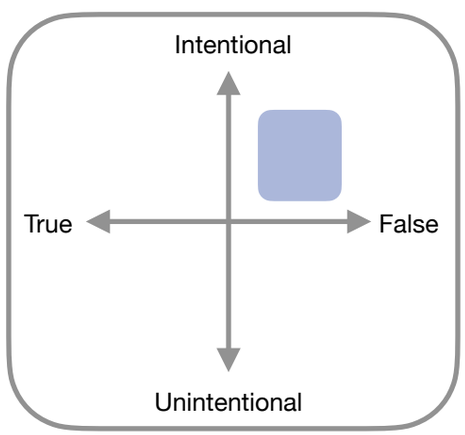

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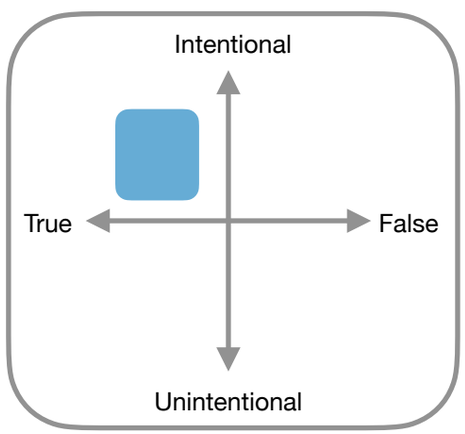

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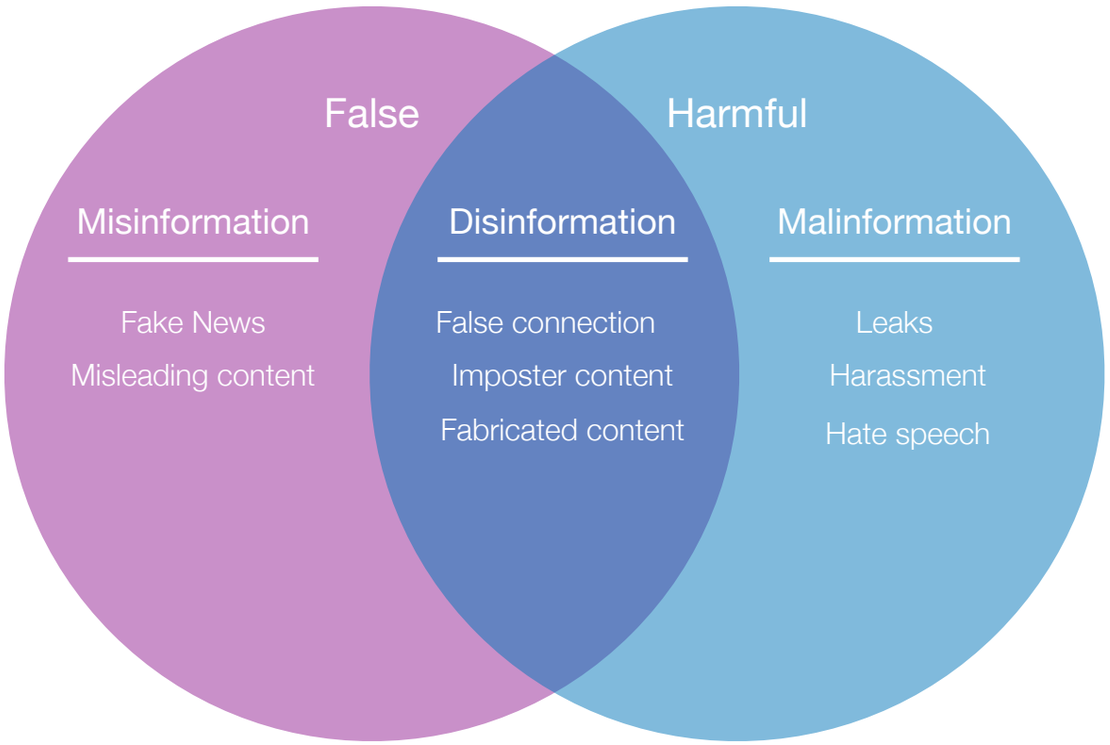

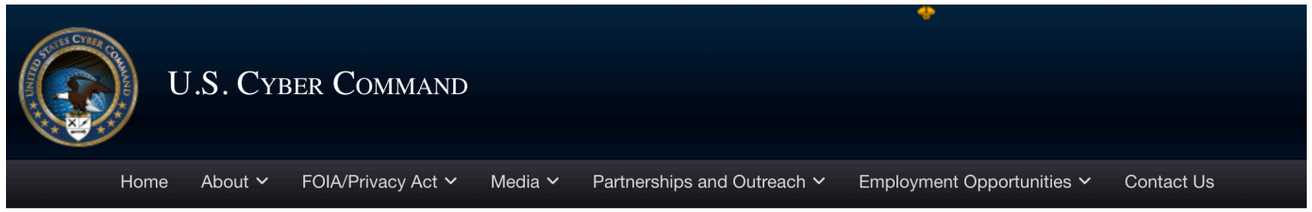

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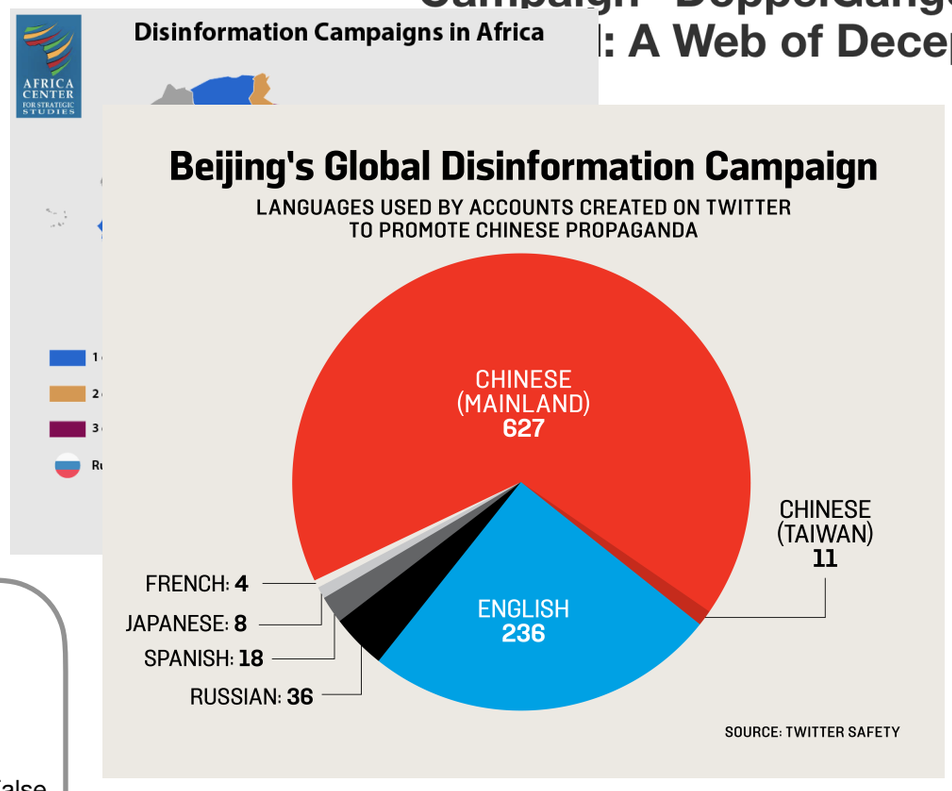

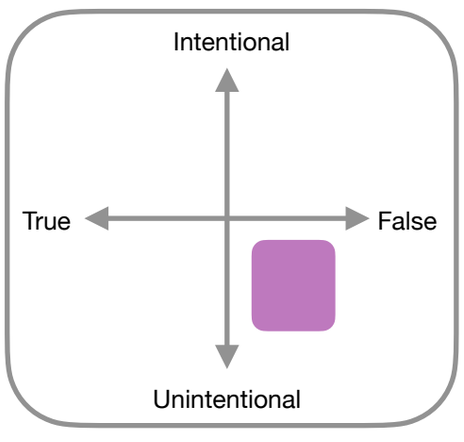

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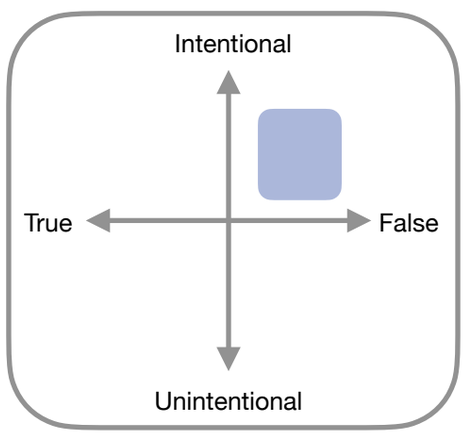

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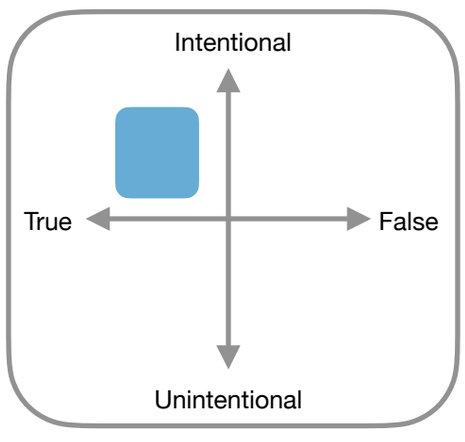

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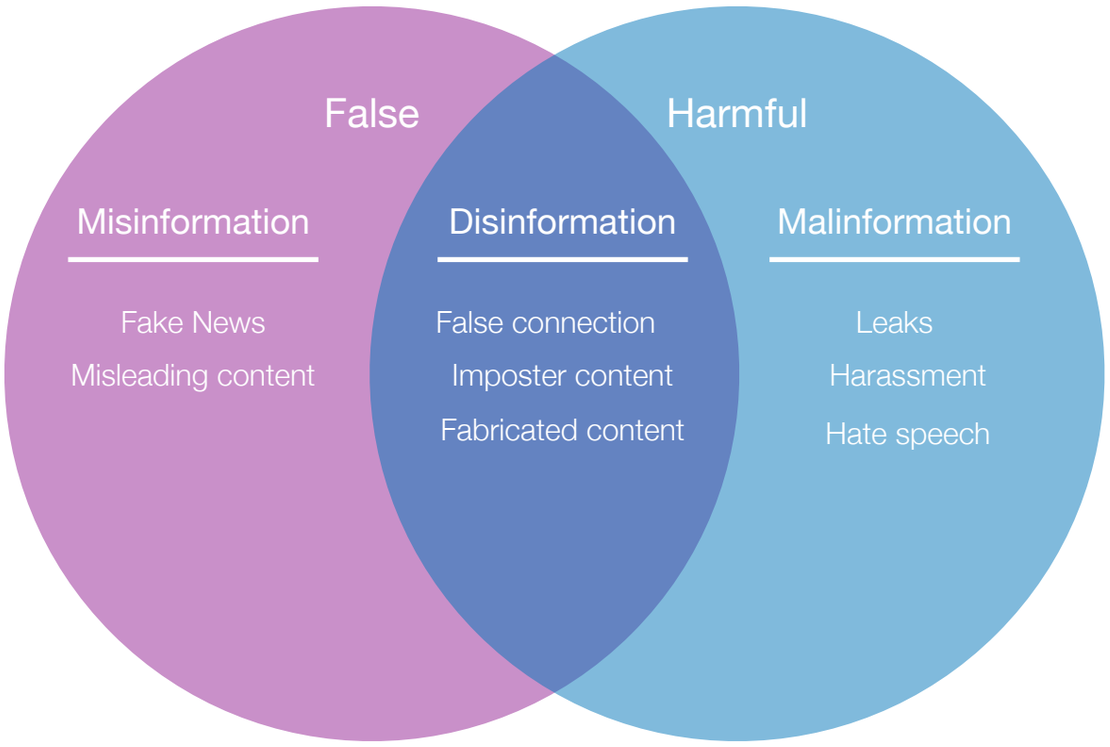

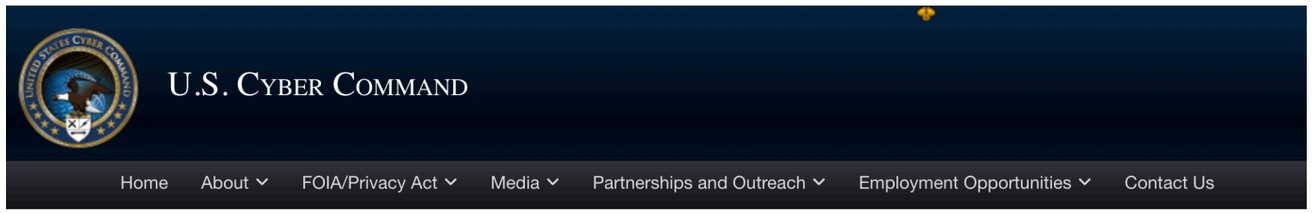

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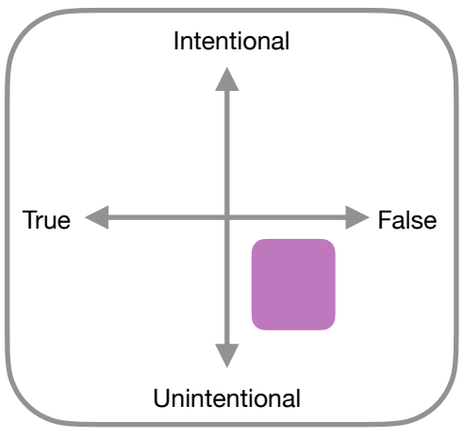

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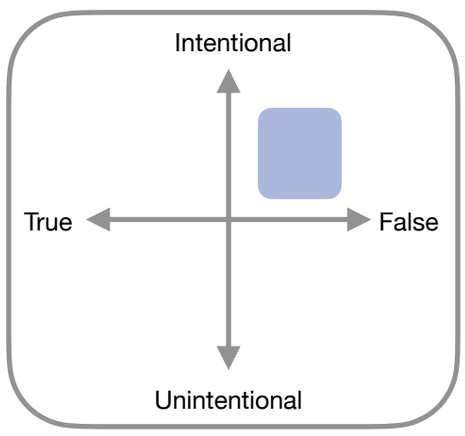

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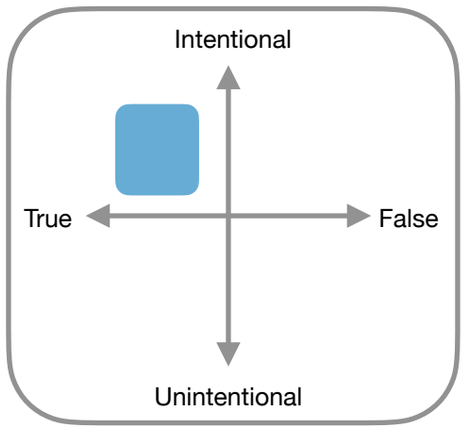

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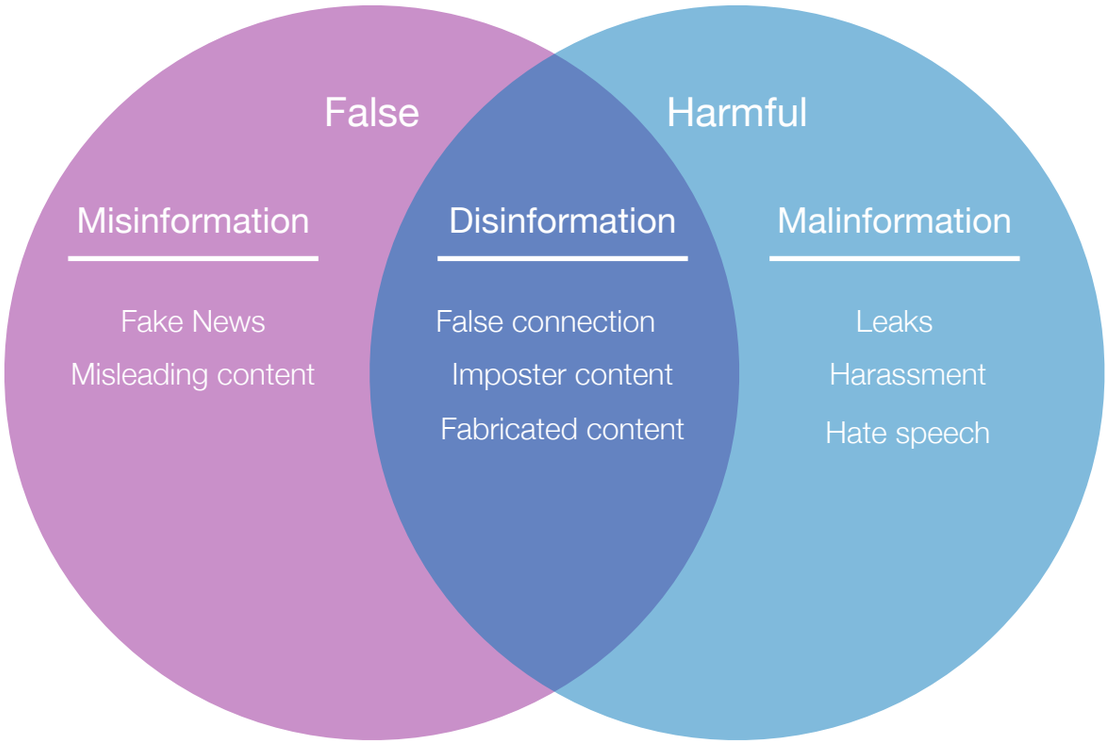

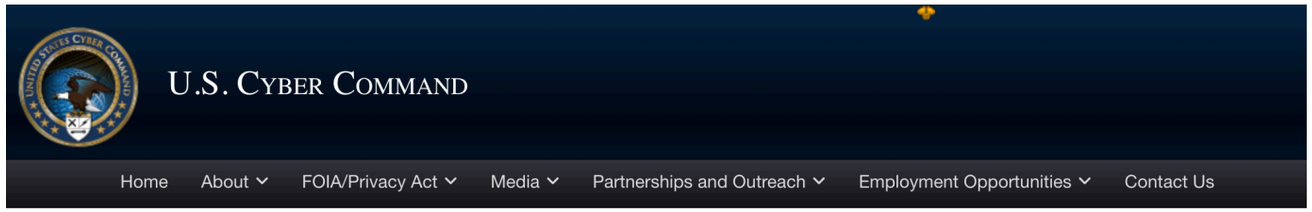

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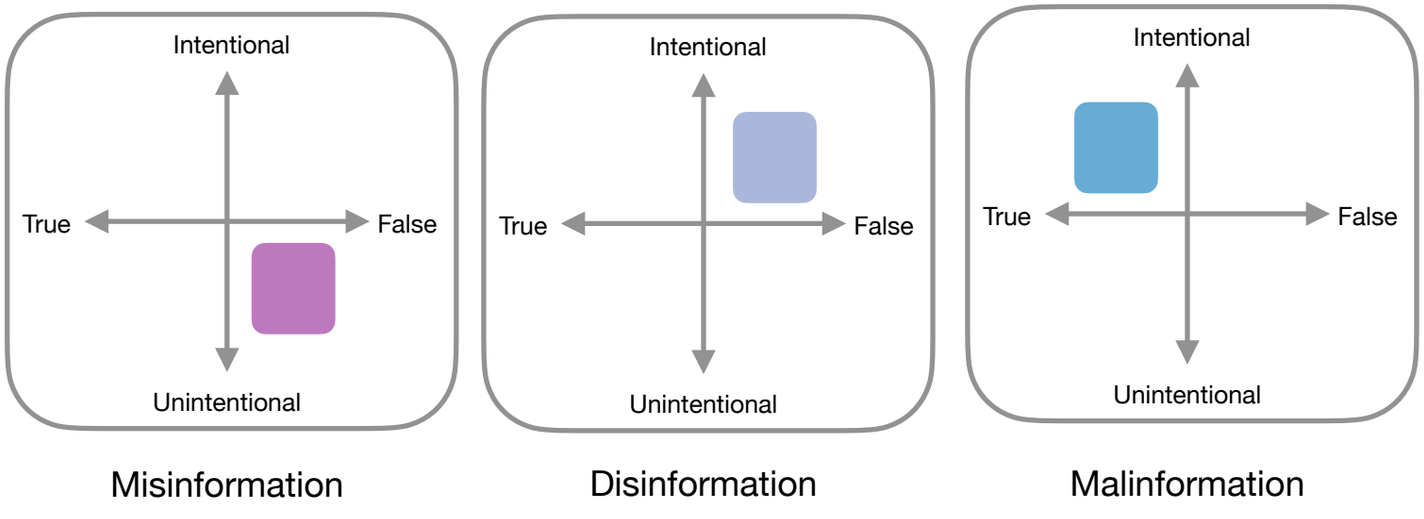

Disinformation Evolution

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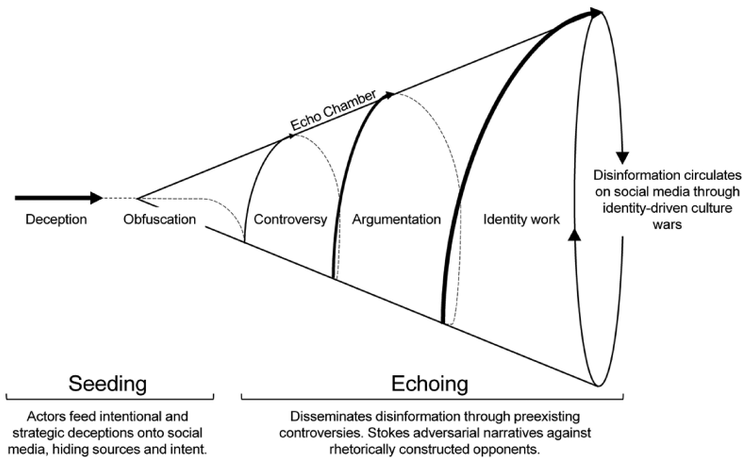

Initiation

Disinformation Evolution

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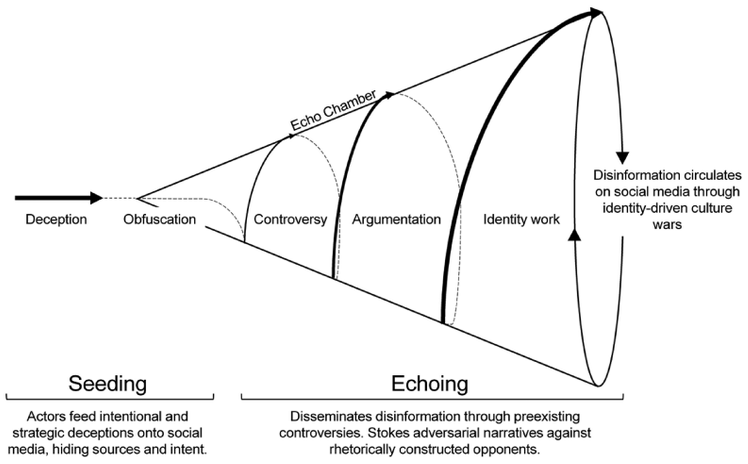

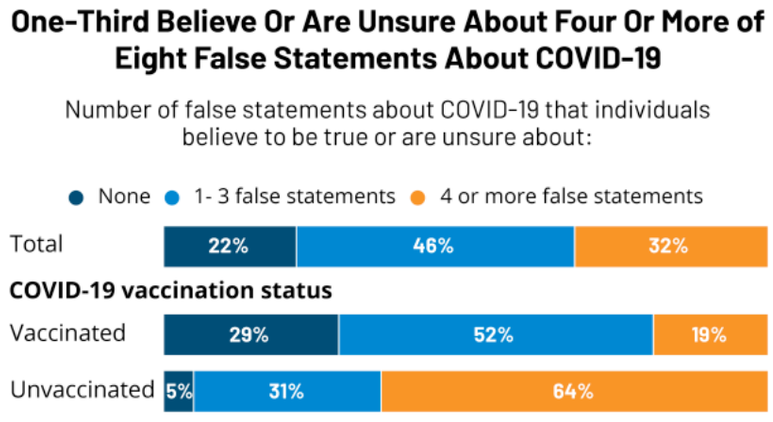

Initiation **Internalization**

Disinformation Evolution

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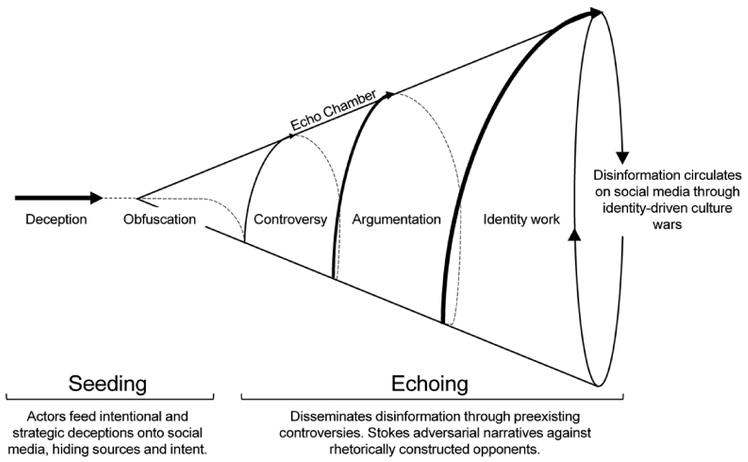

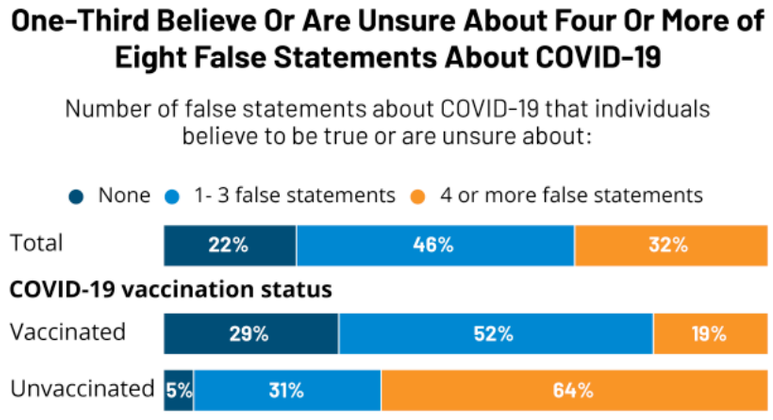

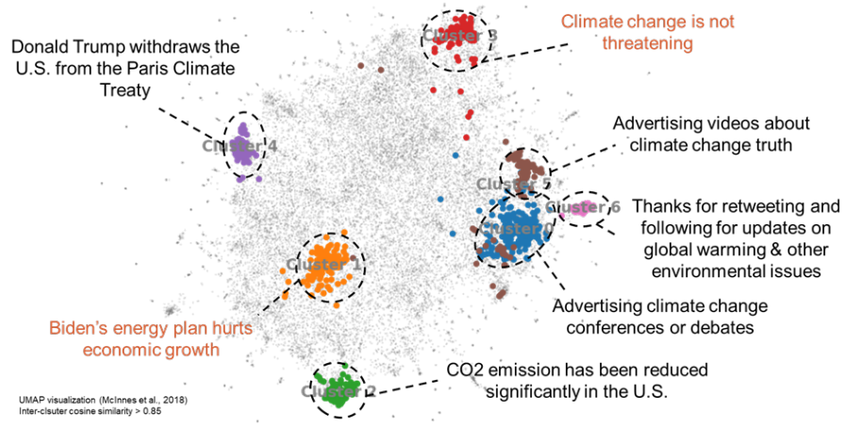

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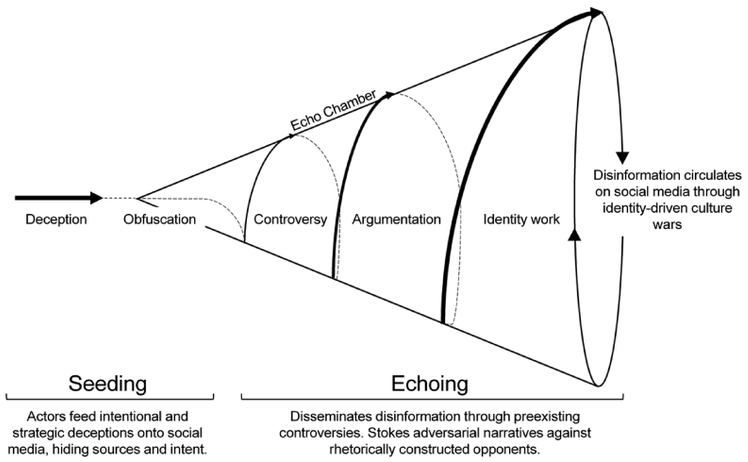

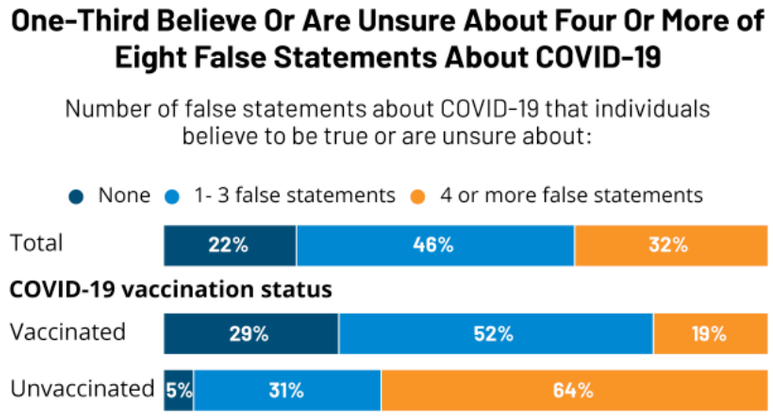

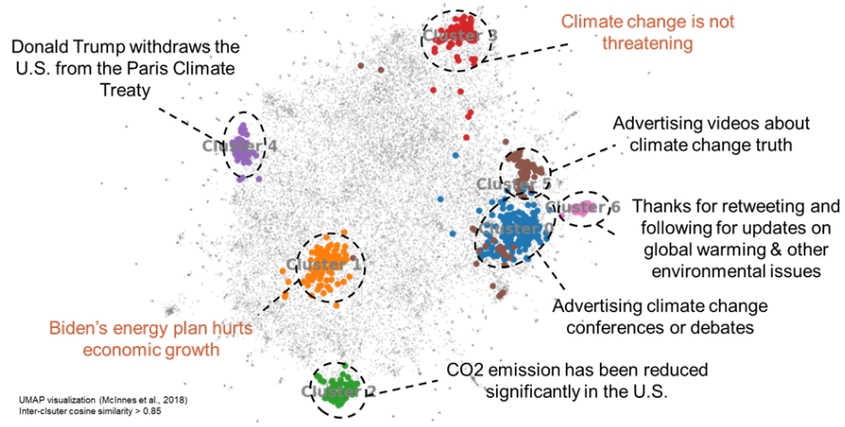

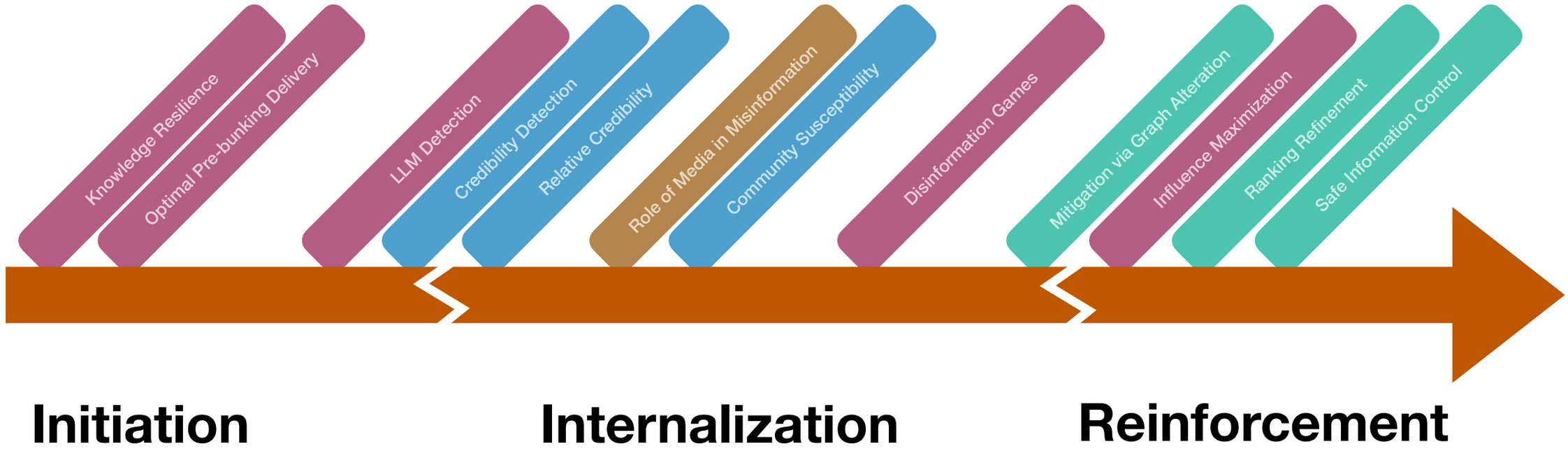

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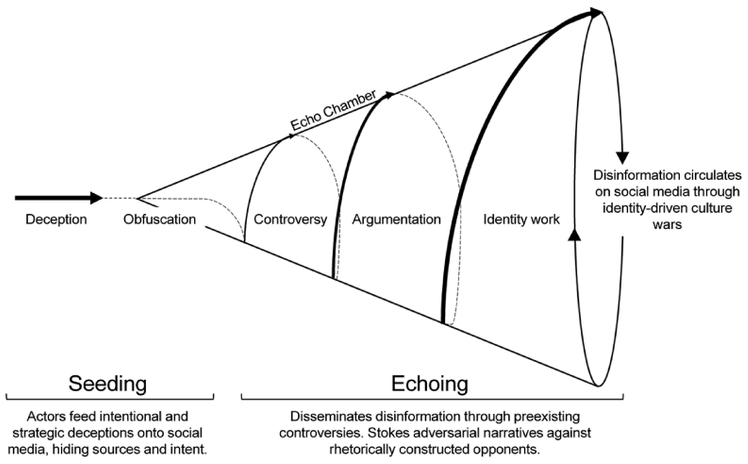

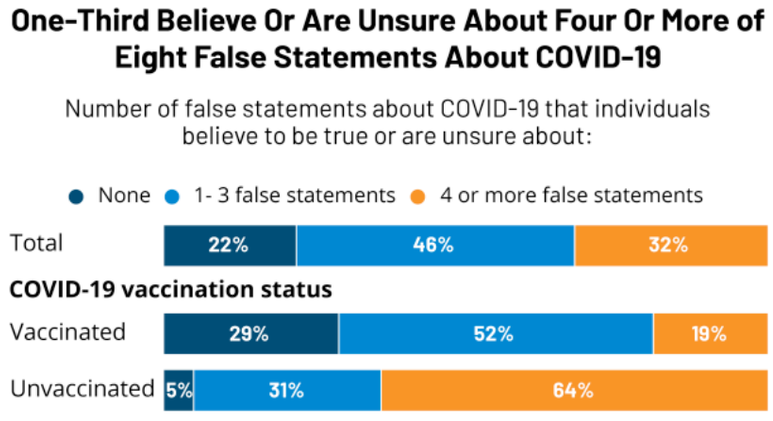

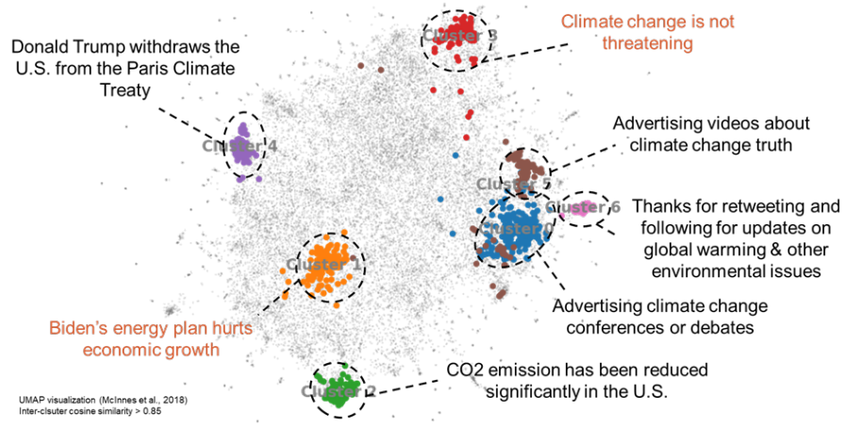

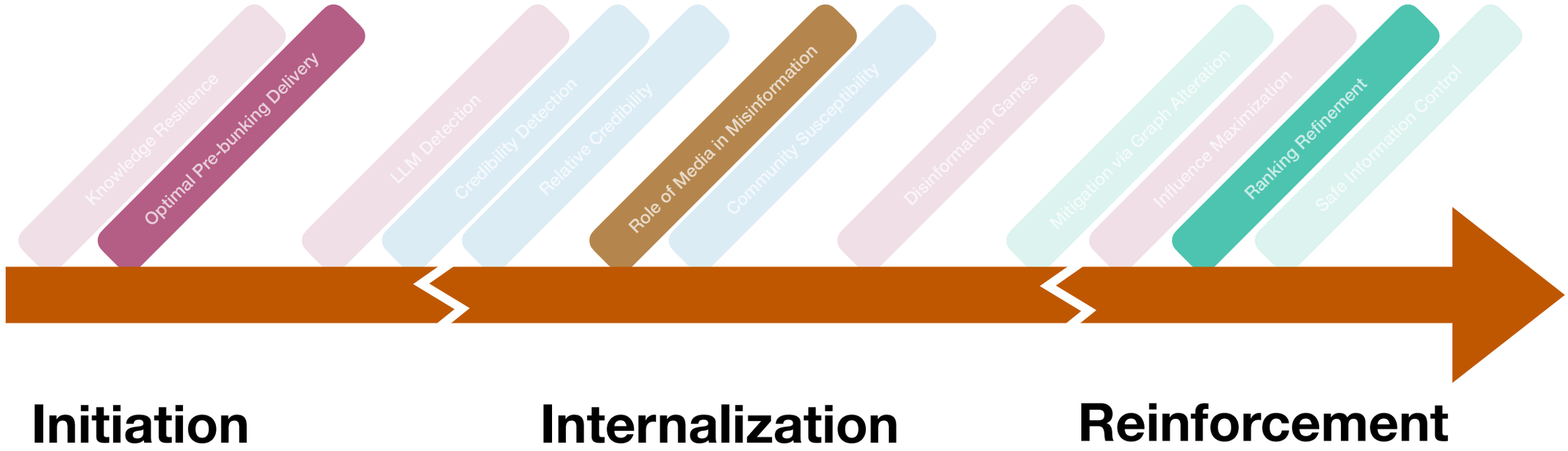

Challenges and Contributions

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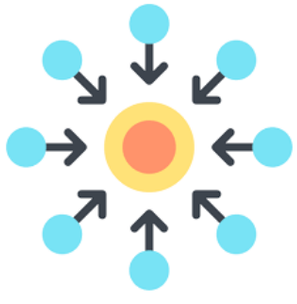
- **Totalitarian:** centralized information management
- **Democratic:** distributed information management



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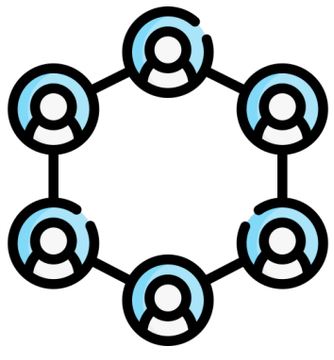

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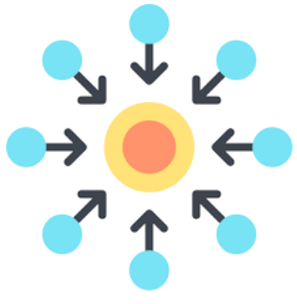

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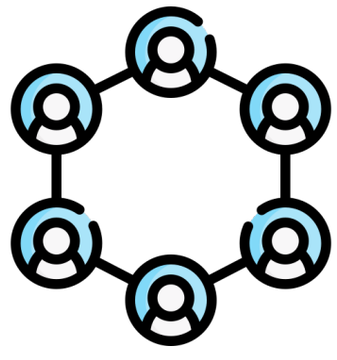

Democratic

Feasible Solutions

- Democratic
- Resilient
- Safe
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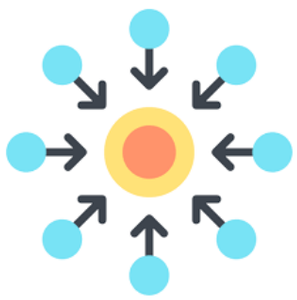

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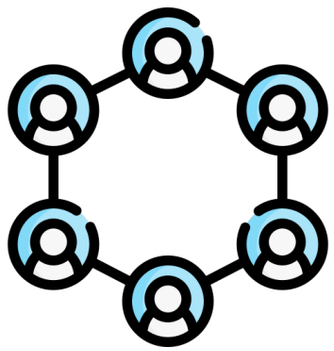

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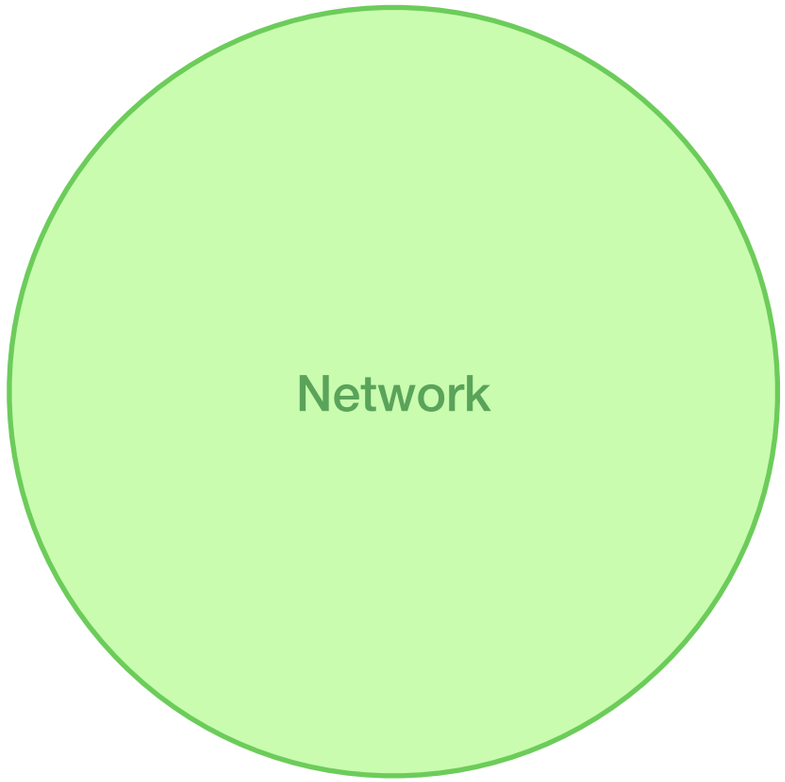

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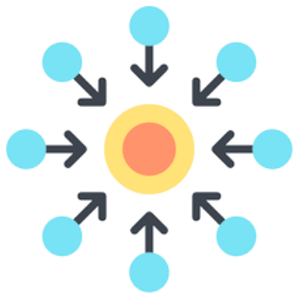

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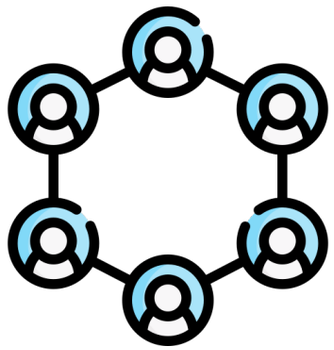

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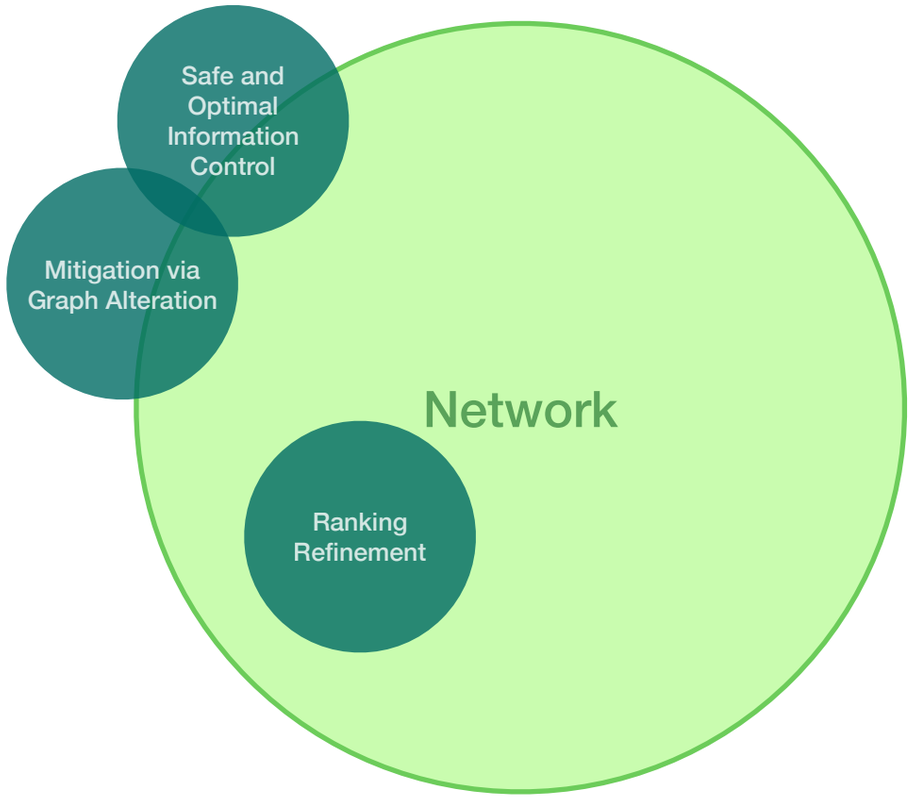

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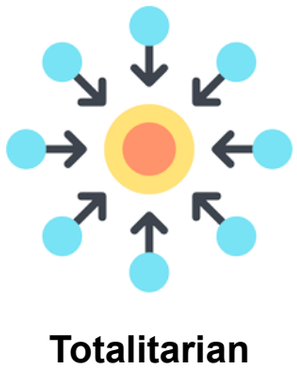

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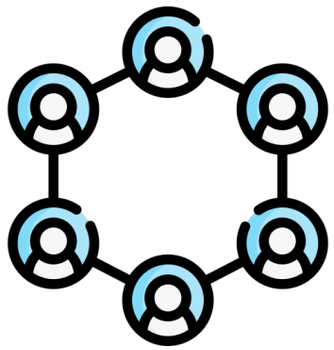

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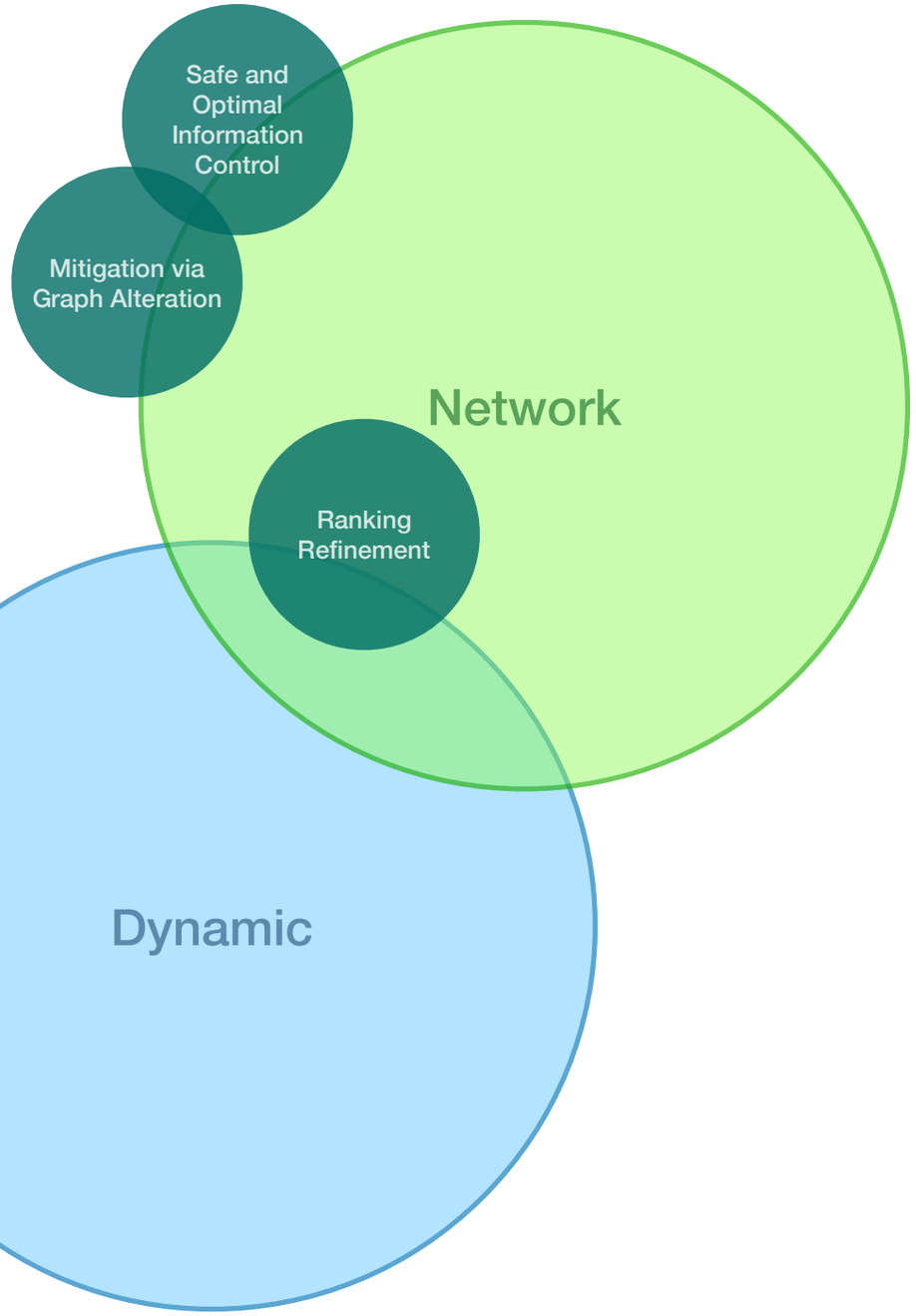

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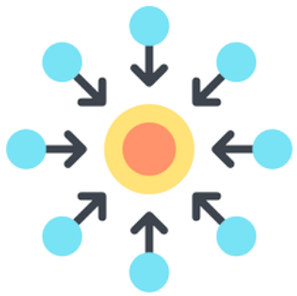

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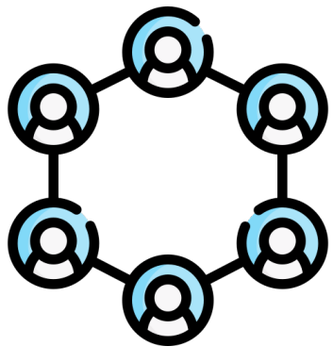

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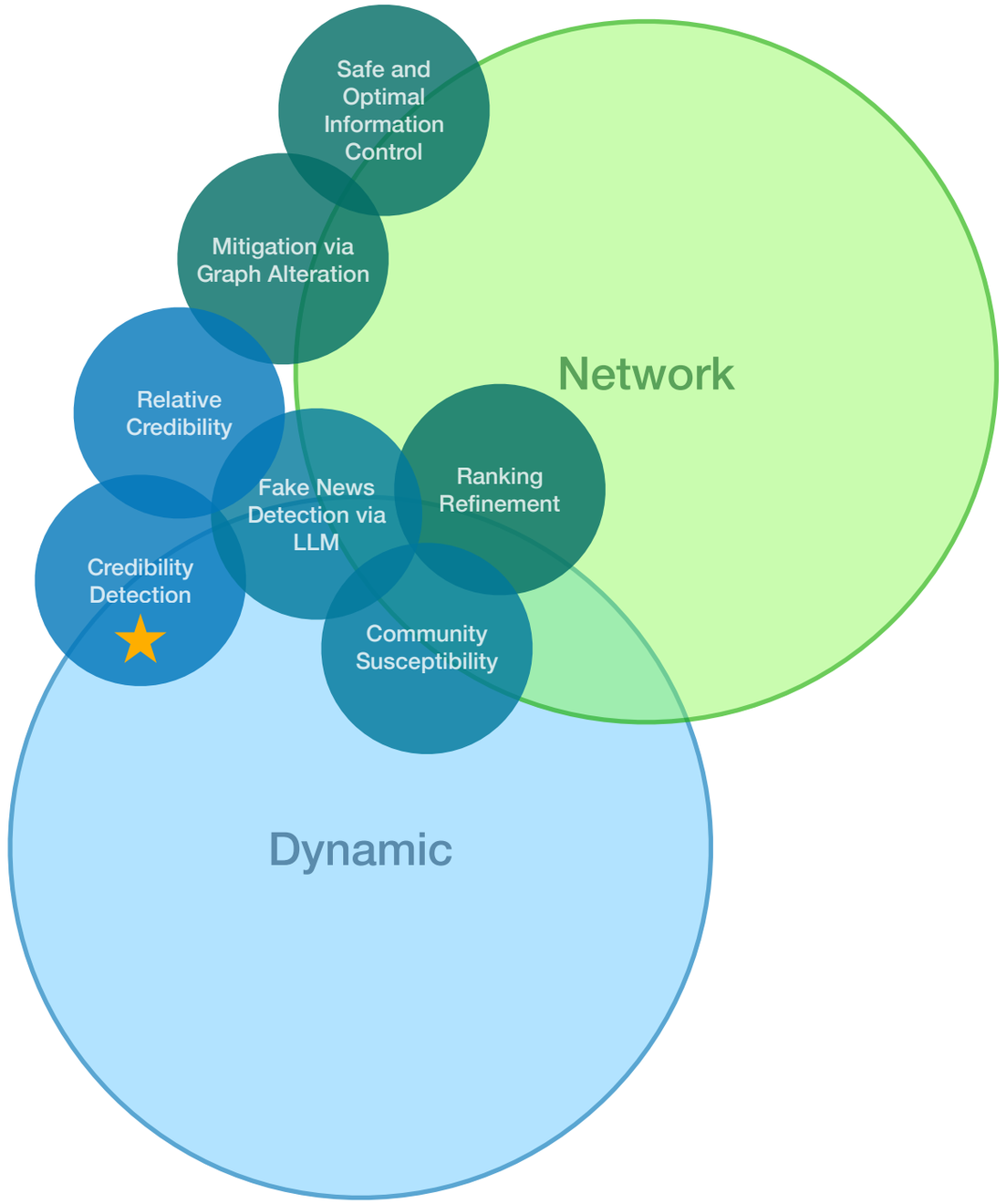

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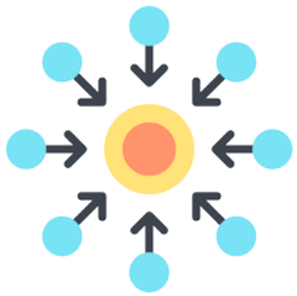

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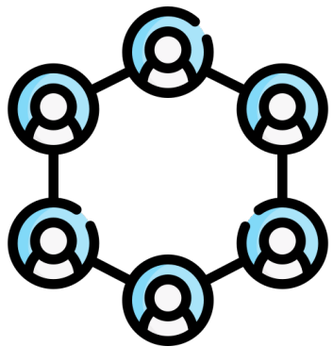

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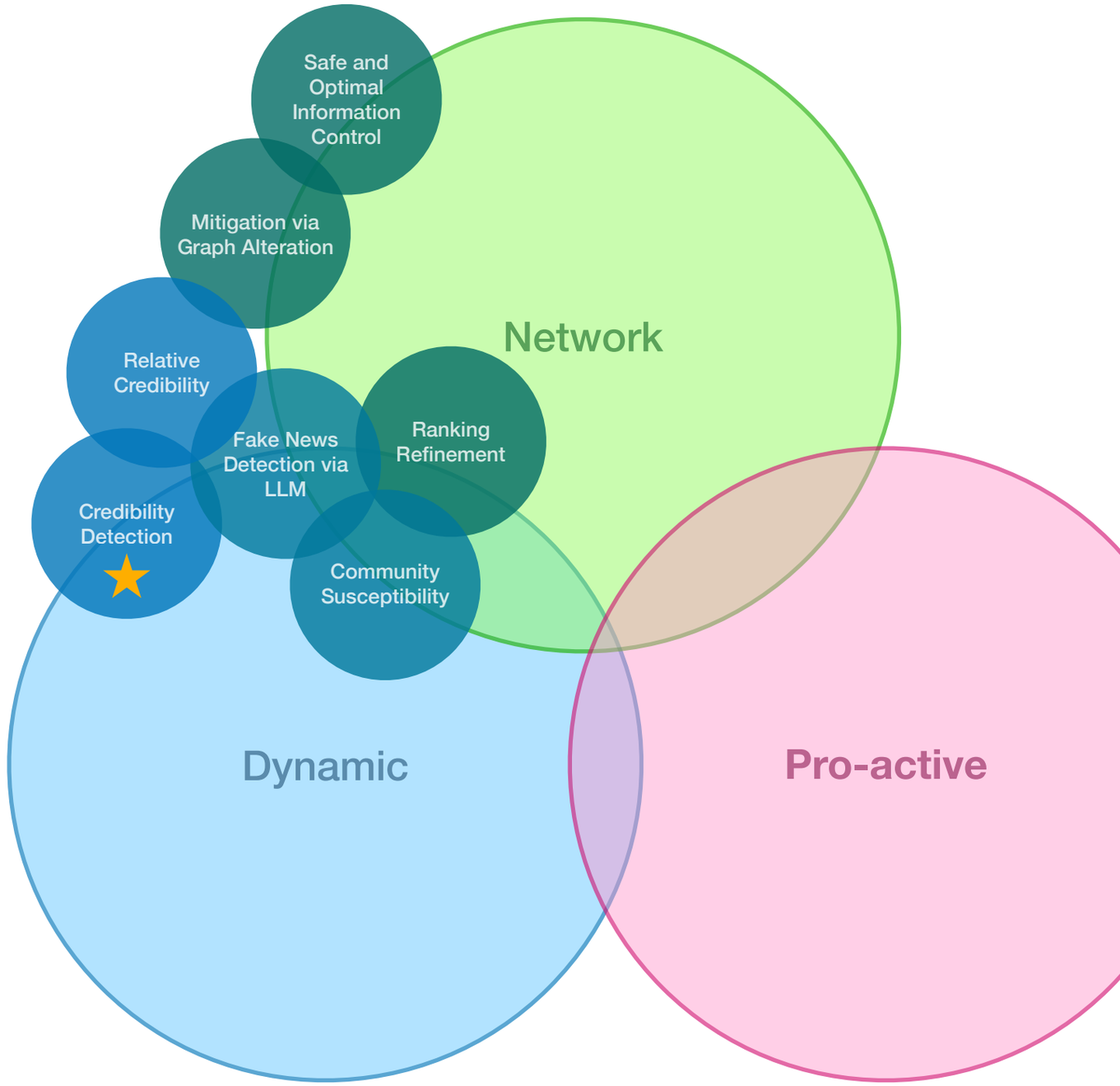

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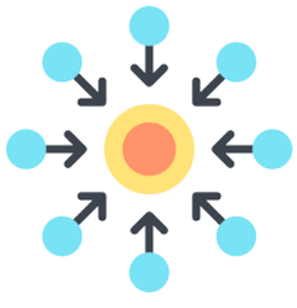

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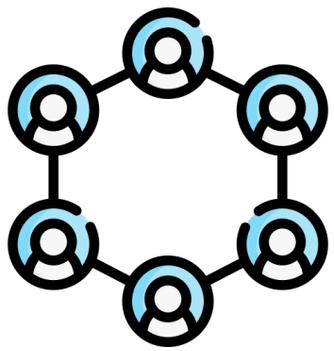

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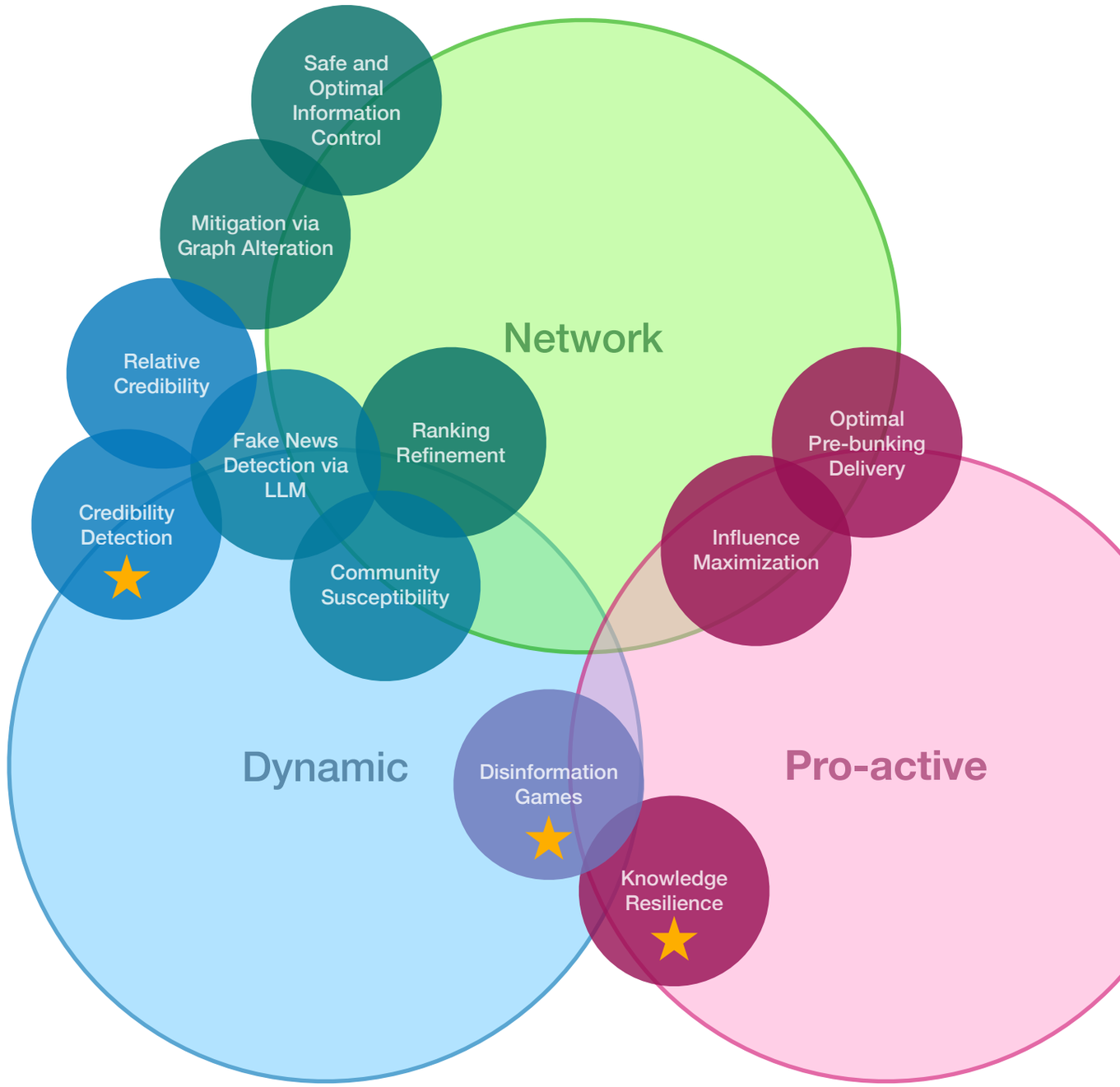

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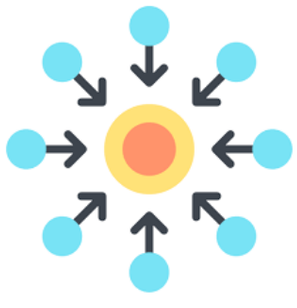

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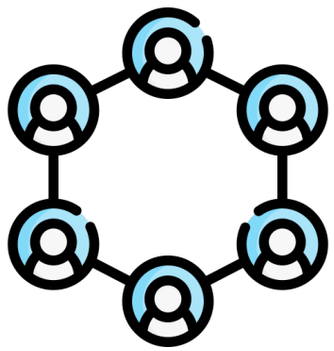

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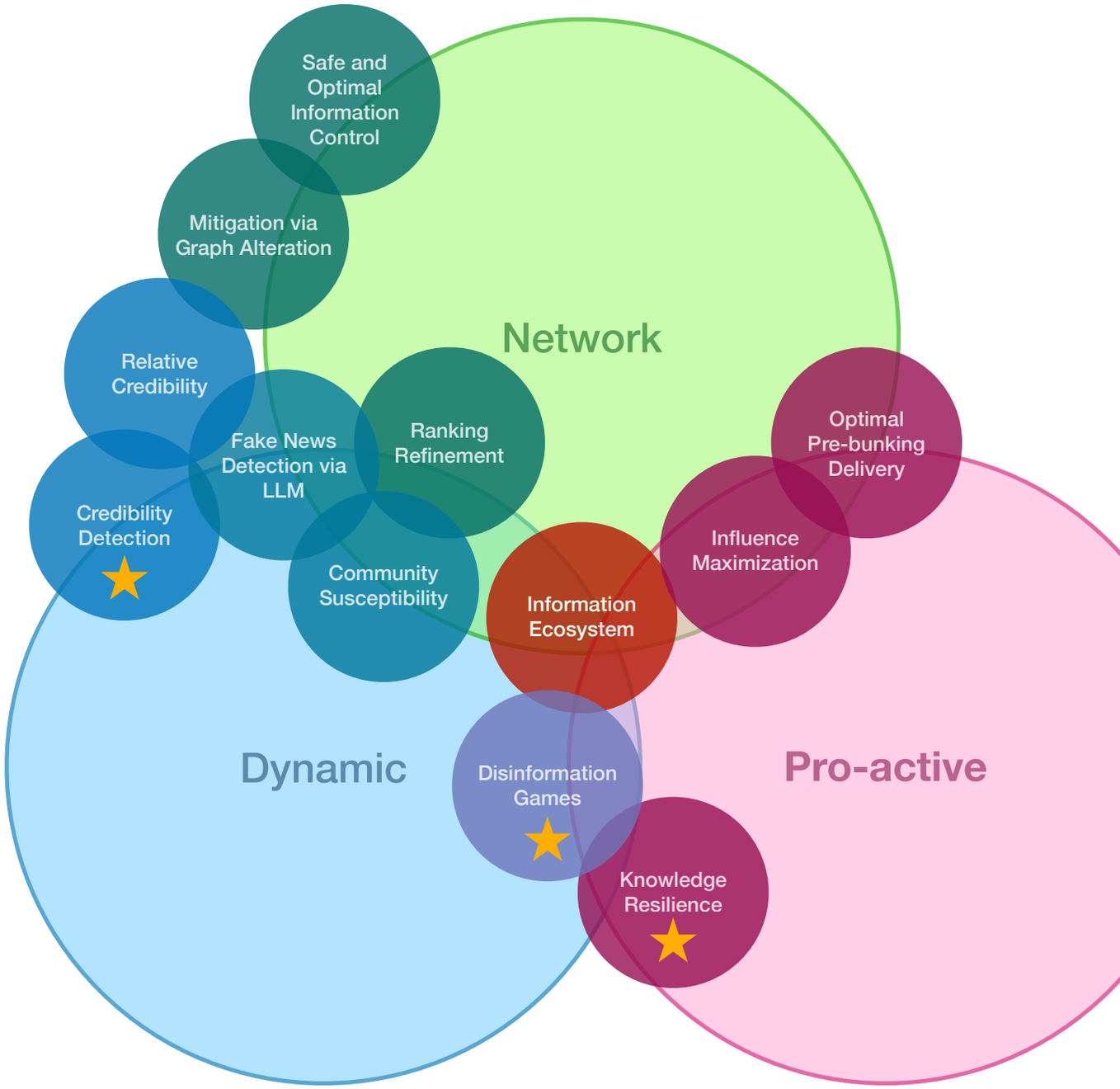

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Modeling Information Environment

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Modeling Information Environment

News Source Credibility

- What is the chance of a news source sharing misinformation?

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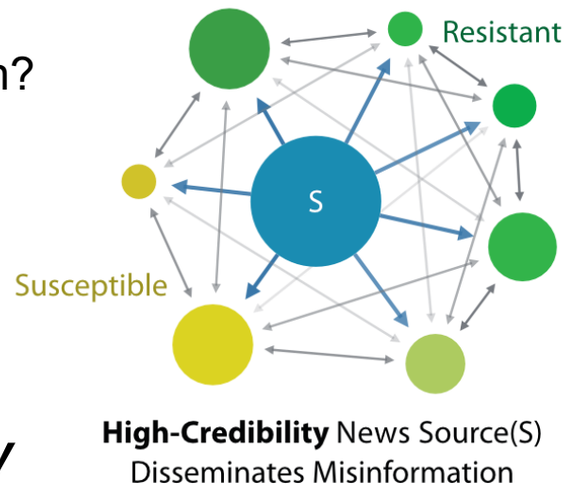
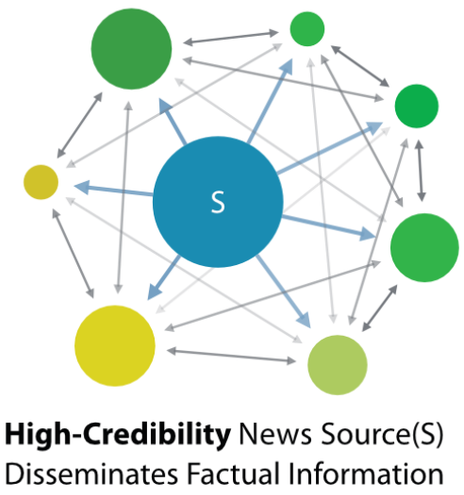
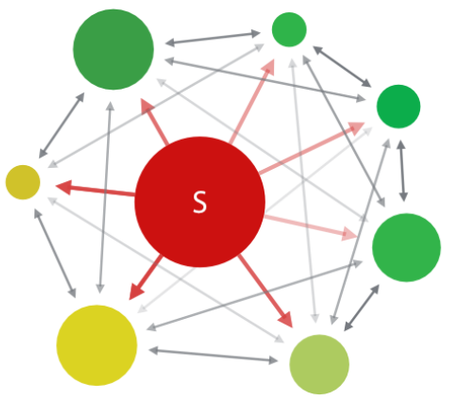


High-Credibility News Source(S) Disseminates Misinformation



High-Credibility News Source(S) Disseminates Factual Information



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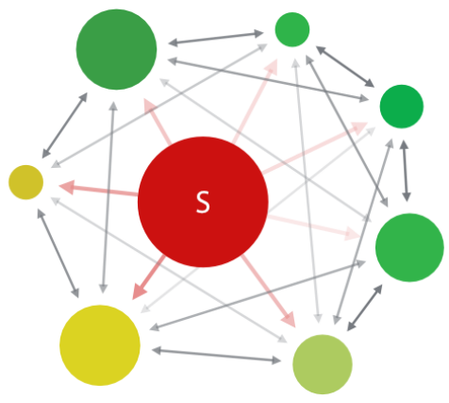

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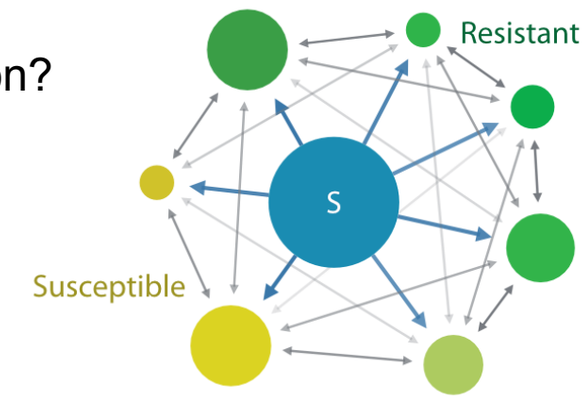
How users beliefs change under exposure to misinformation?

$$x_{t+1}^i = \underbrace{\frac{a}{A_t^i}\sum_{j=1}^{N}\phi(|x_t^i - x_t^j|)(x_t^j - x_t^i)}_{\text{Social influence}} + \underbrace{\frac{b}{B_t^i}\sum_{m=1}^{M}\psi(|x_t^i - y^m|, c_t^m, a_t^m, s^i)(y^m - x_t^i)}_{\text{Media influence}} + \sigma w_t^i,$$



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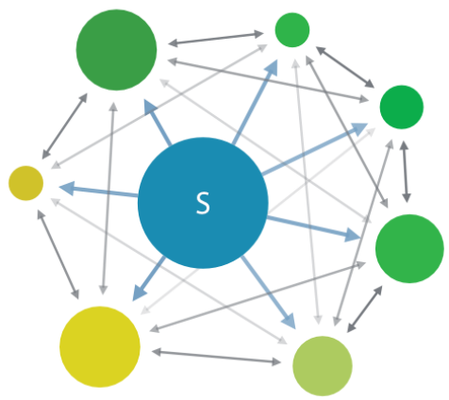

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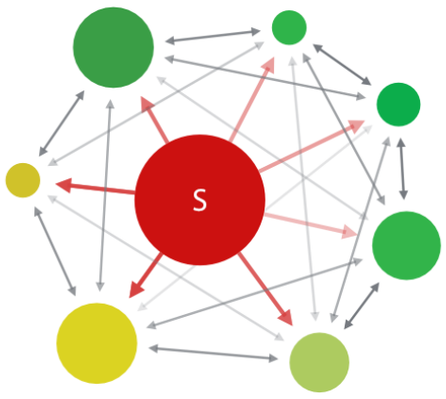

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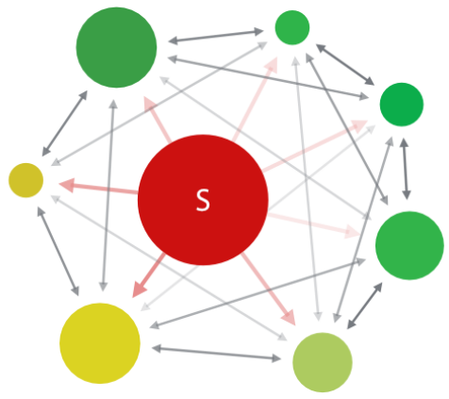

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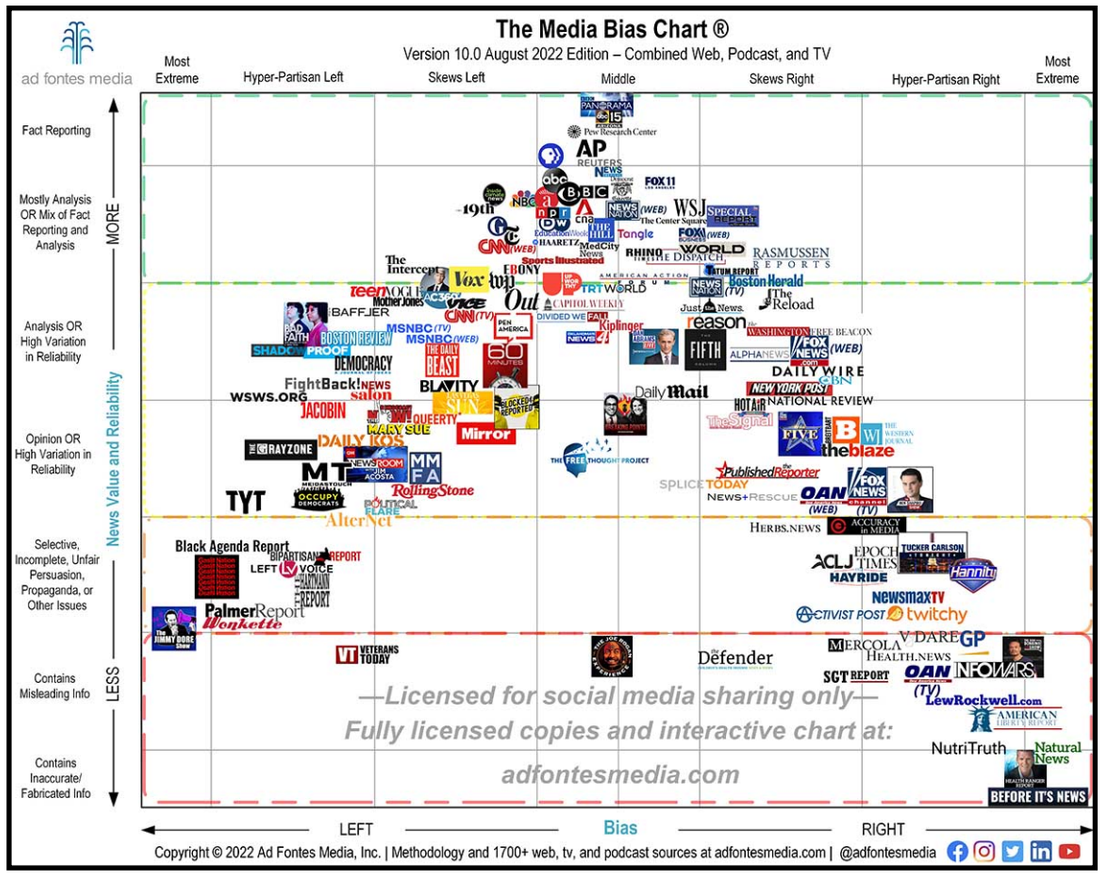

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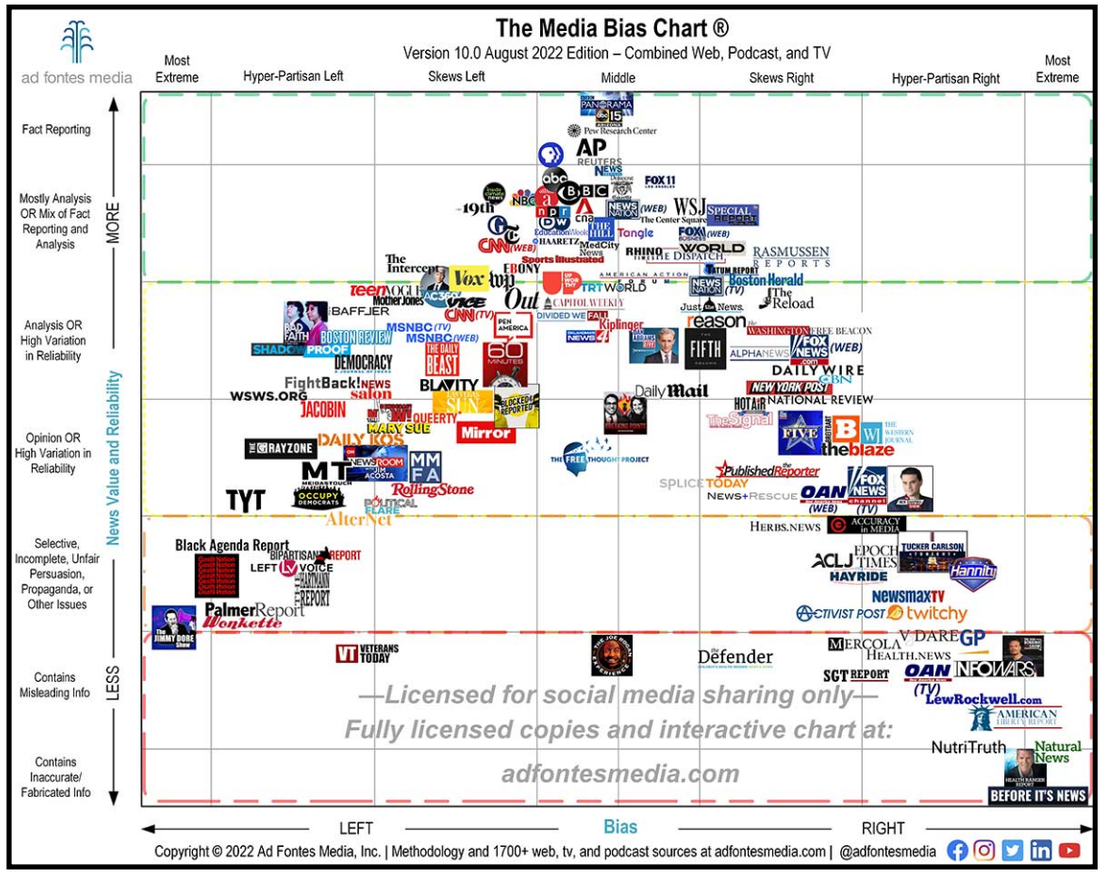

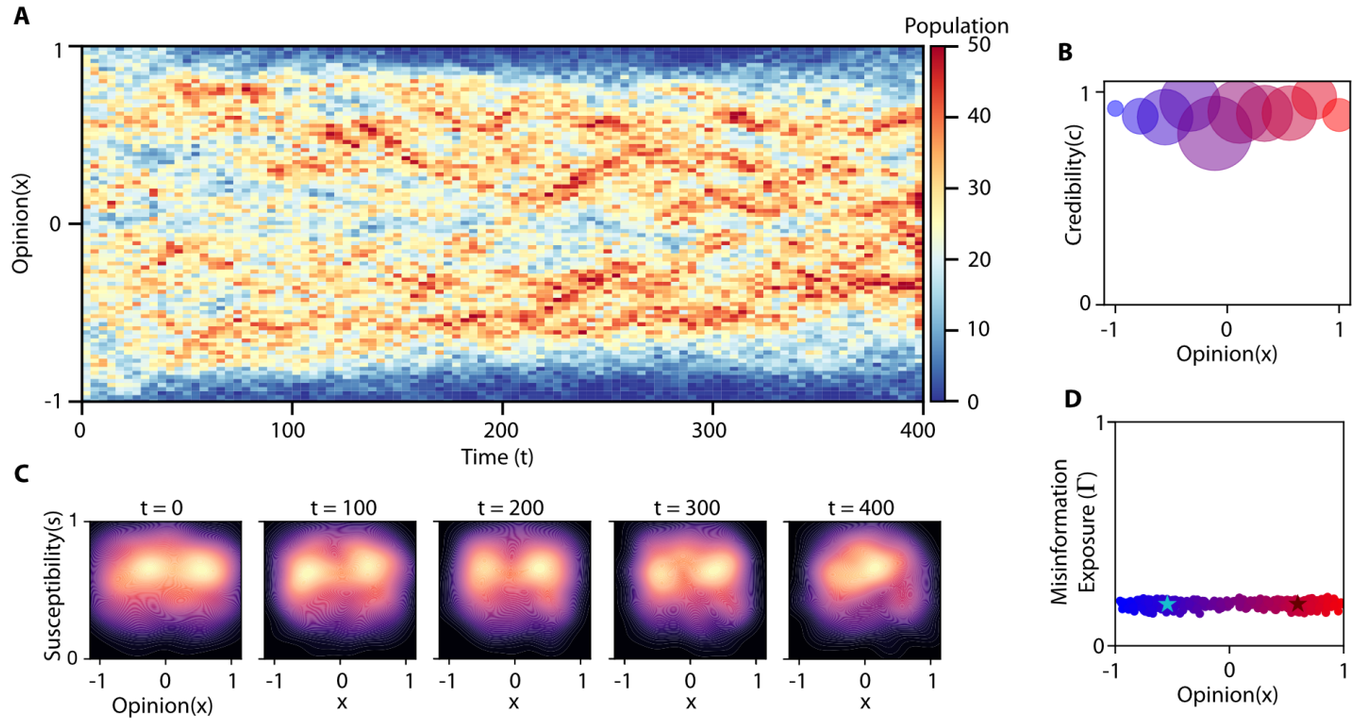

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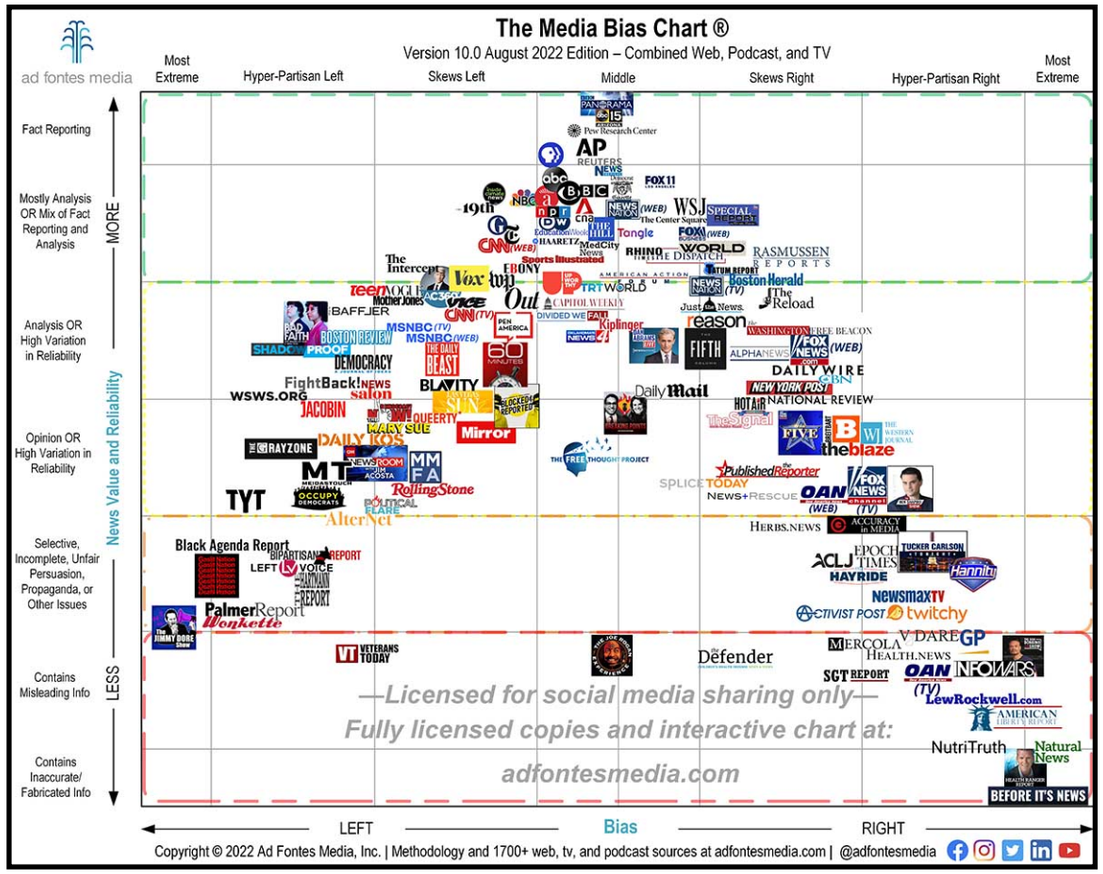

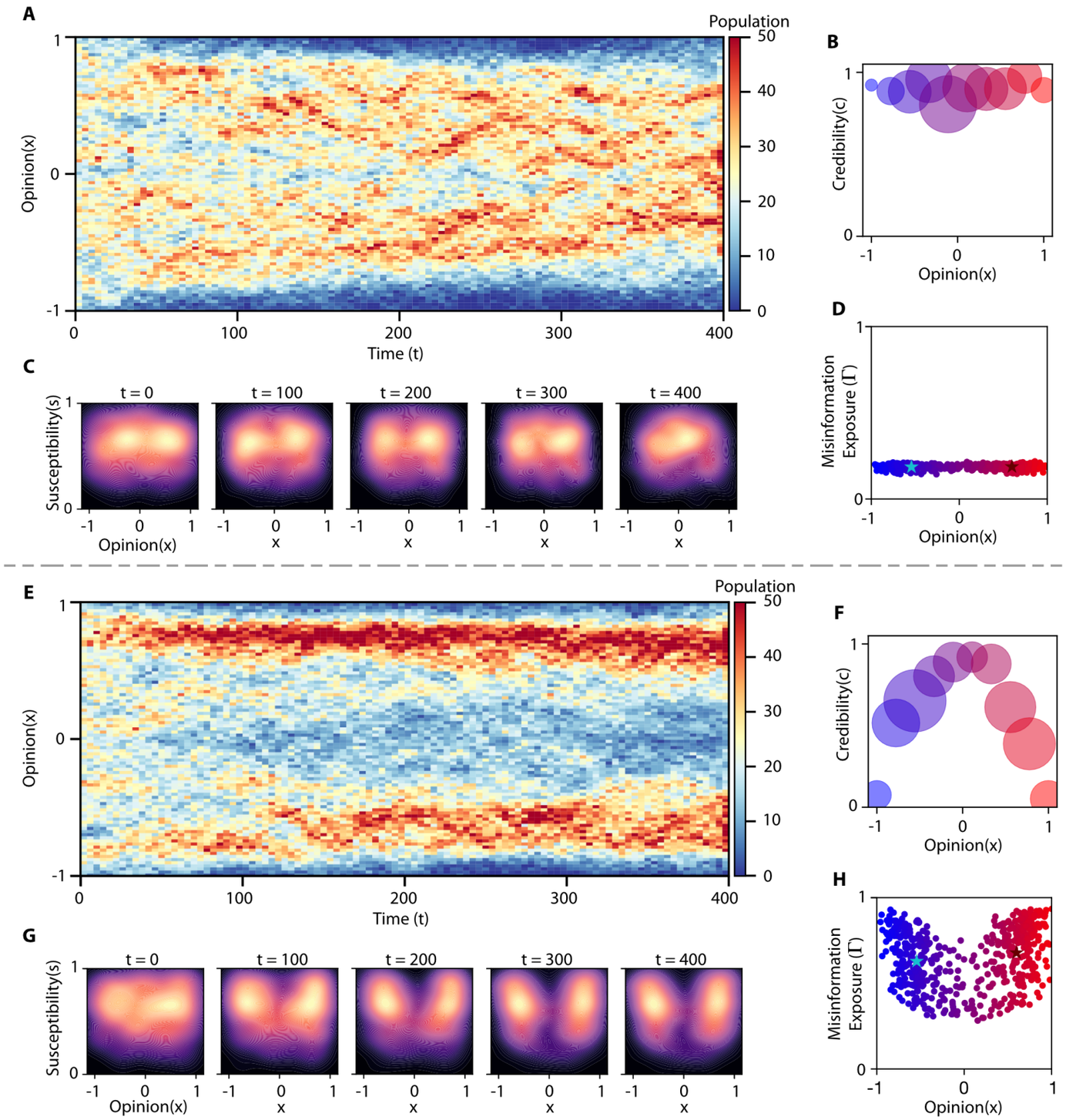

[1] Amini, Arash, et al. *How Media Competition Fuels the Spread of Misinformation*. Science Advances [Under review]

Modeling Information Enviroment

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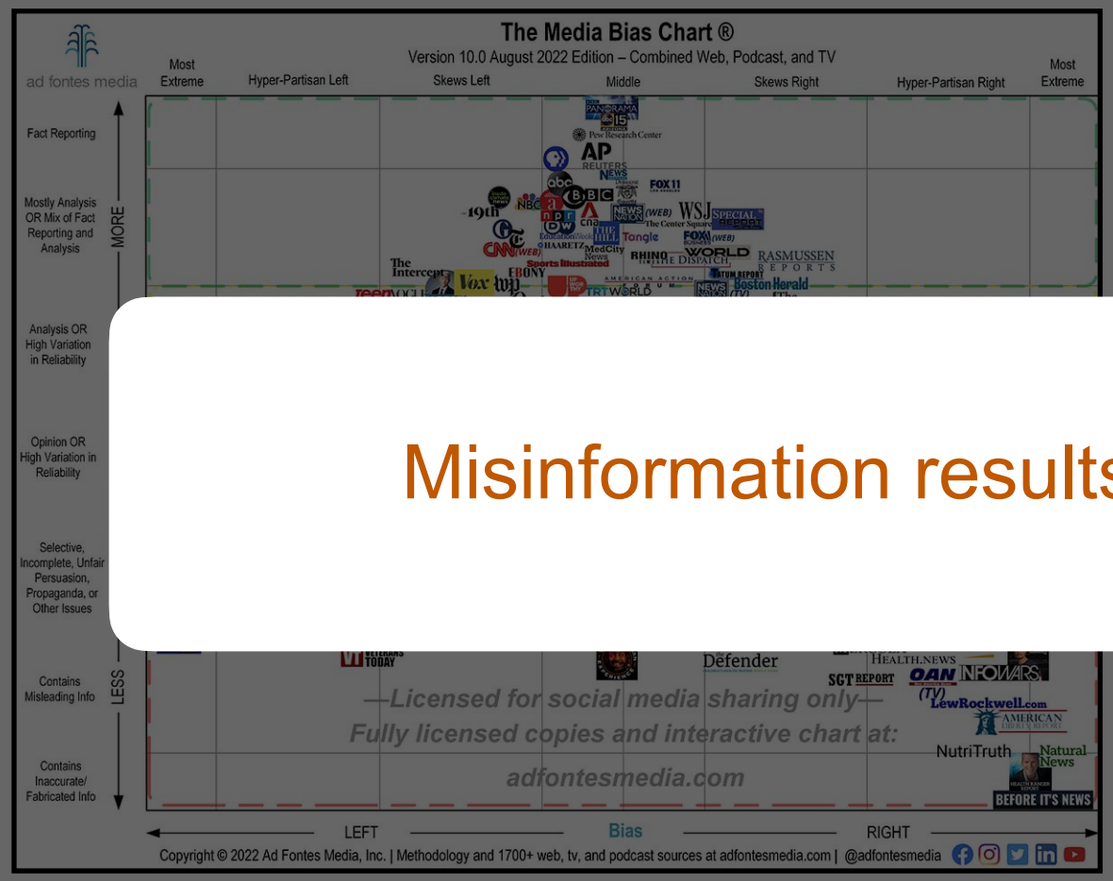
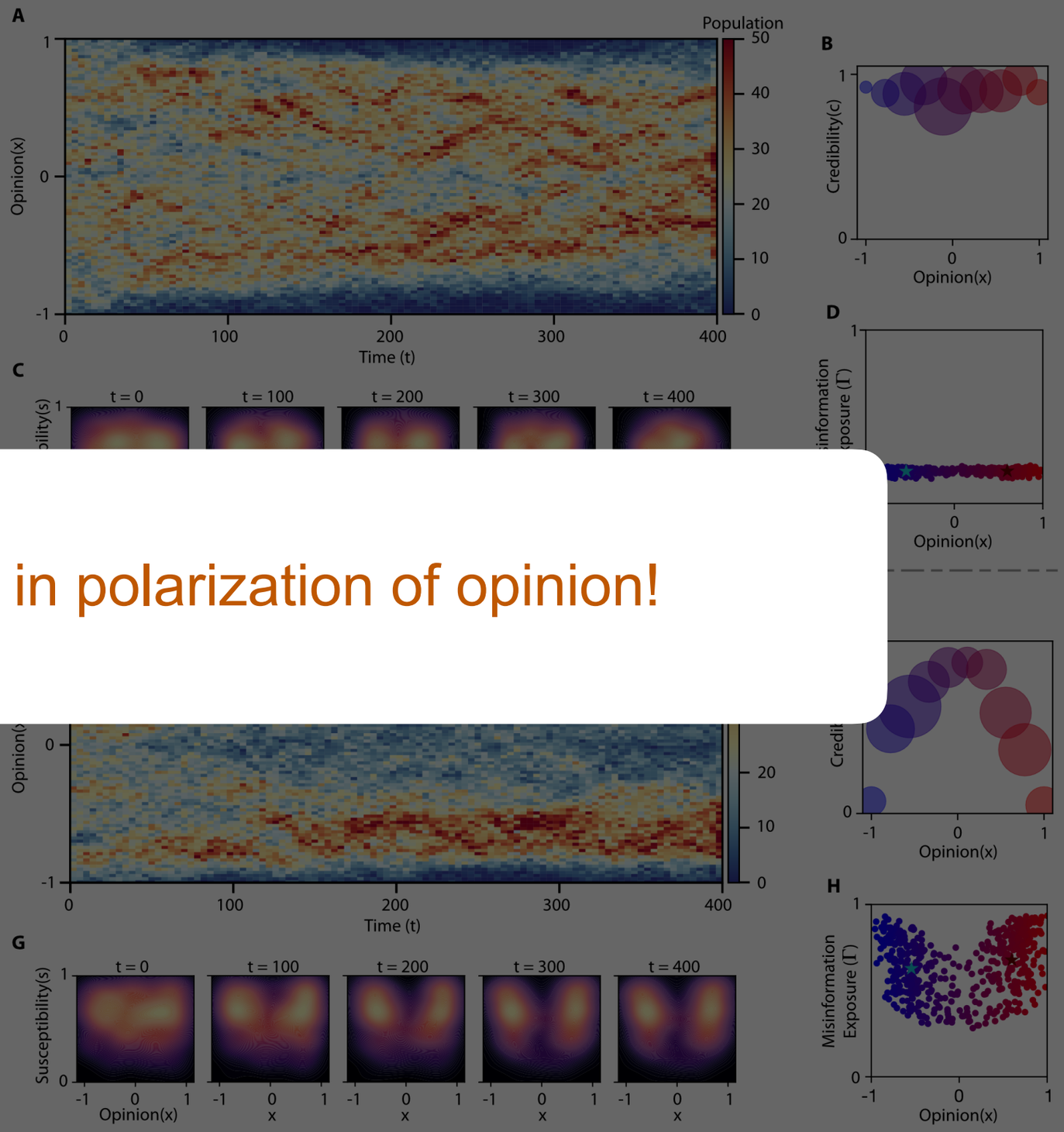
Source Credibility



Misinformation results in polarization of opinion!



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Gain Influence Loose Credibility

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$$\max_{\pi^L} \min_{\pi^R} \qquad J := \mathbb{E}\Big[\sum_{k=1}^{\infty} \gamma^k r(x_k)\Big]$$

$$x_{t+1}^i = \underbrace{\frac{a}{A_t^i}\sum_{j=1}^{N}\phi(|x_t^i - x_t^j|)(x_t^j - x_t^i)}_{\text{Social influence}} + \underbrace{\frac{b}{B_t^i}\sum_{m=1}^{M}\psi(|x_t^i - y^m|, c_t^m, a_t^m, s^i)(y^m - x_t^i)}_{\text{Media influence}} + \sigma w_t^i,$$

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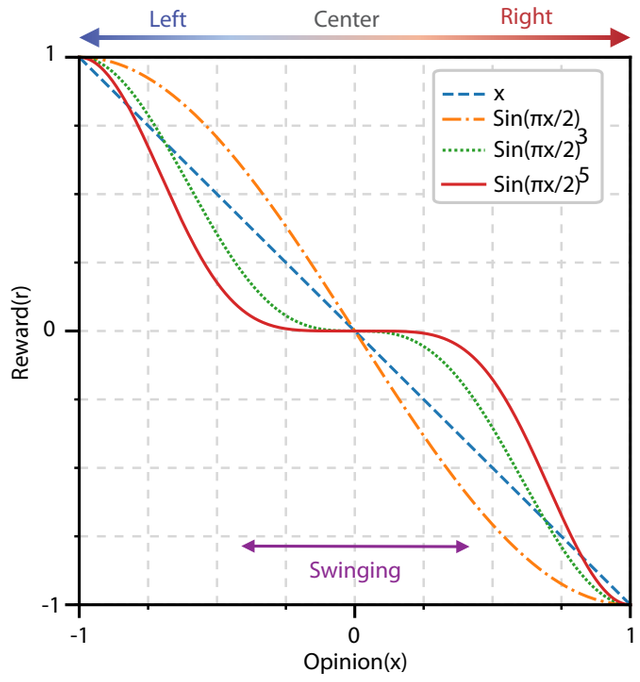

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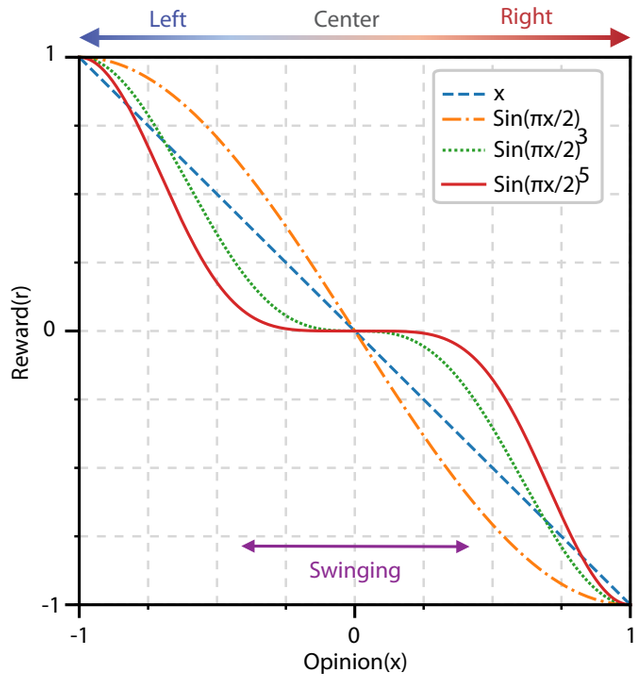

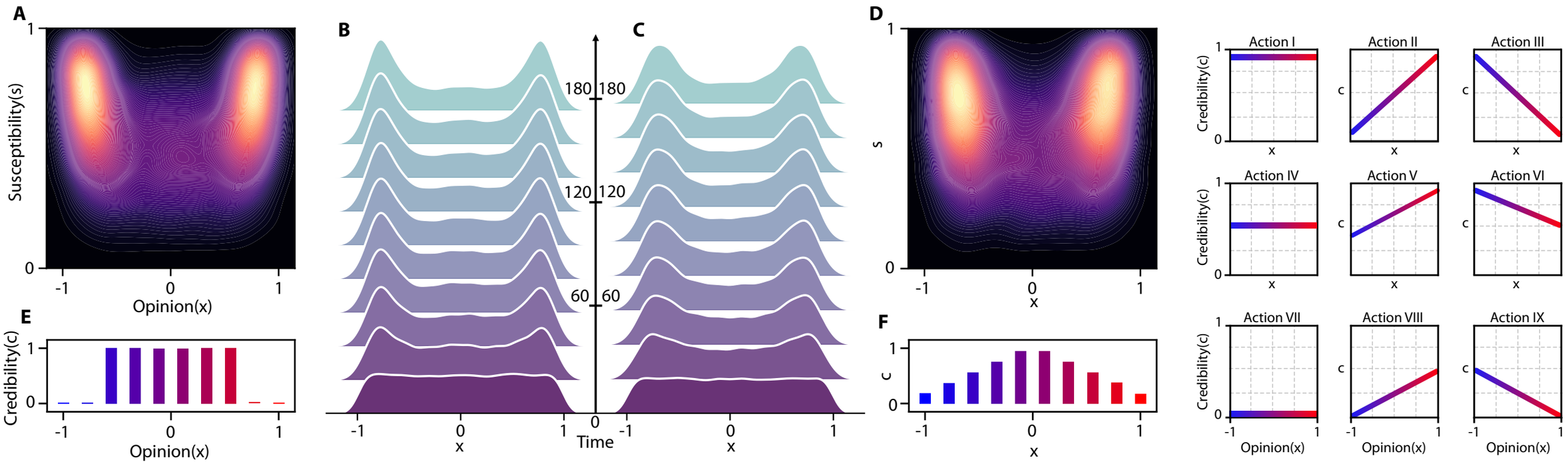

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Arm Race

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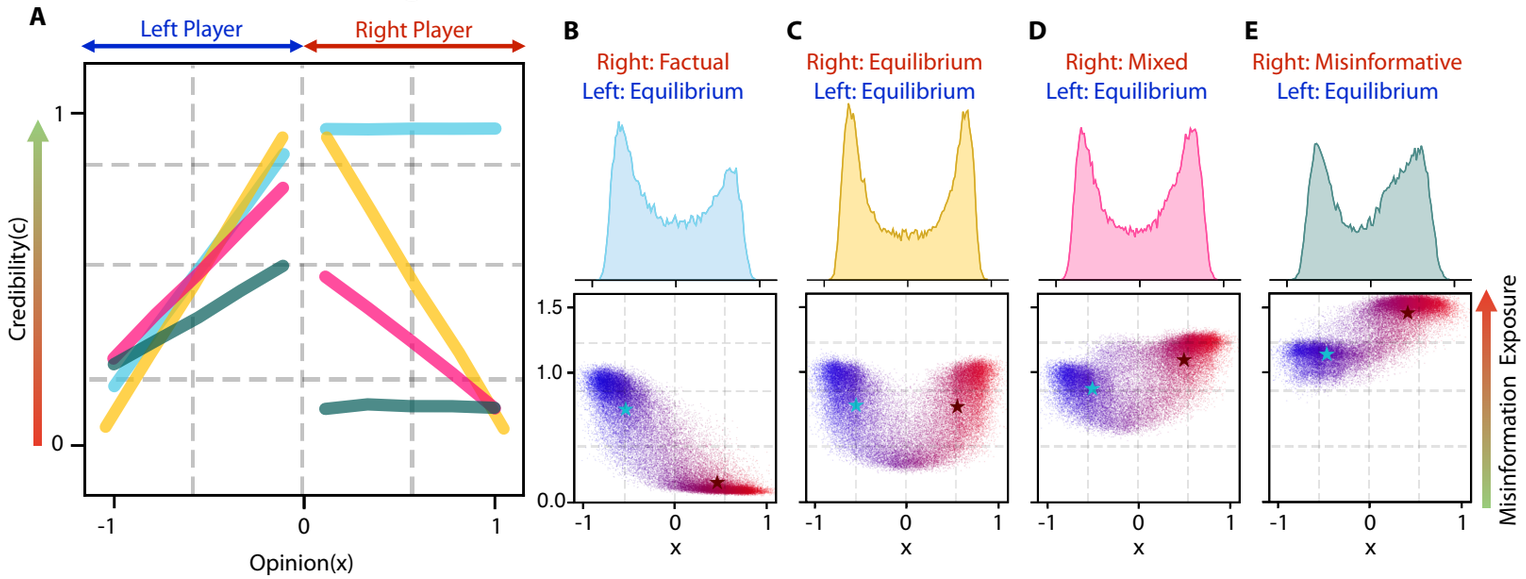
If a player **increases misinformation dissemination** below equilibrium, the **optimal response** of the other player leads to *greater misinformation sharing*.



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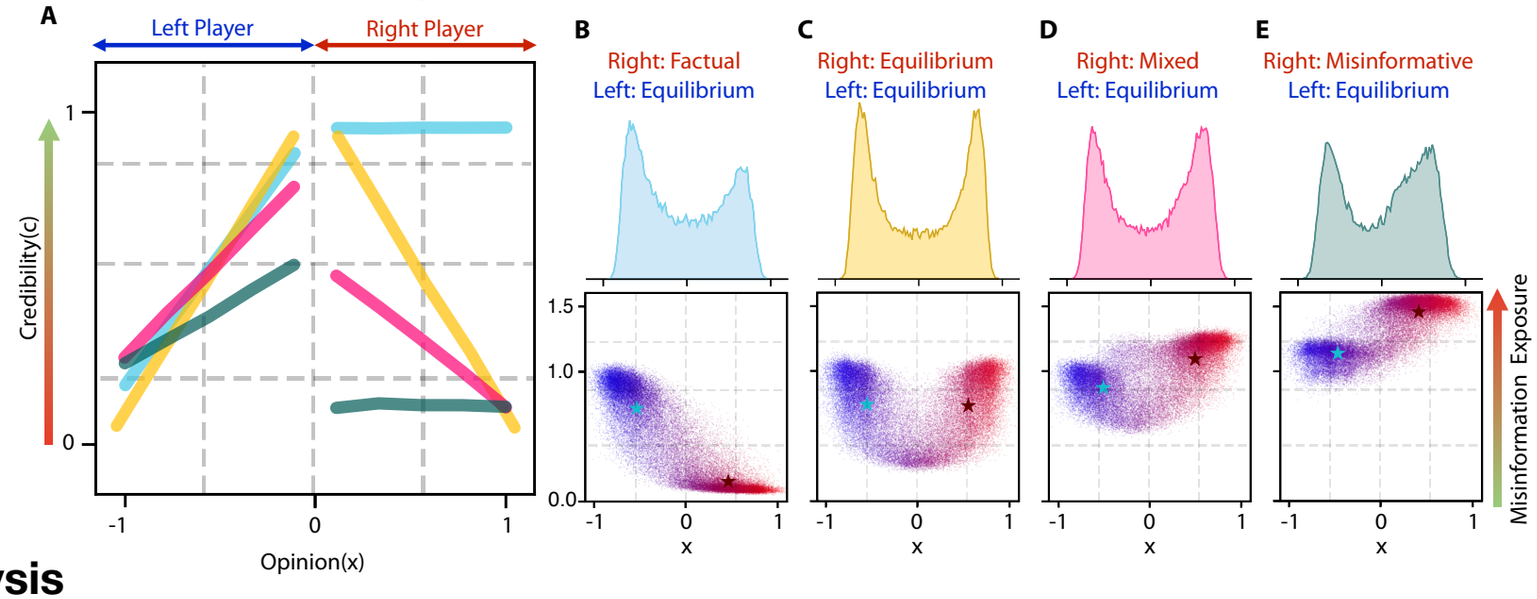
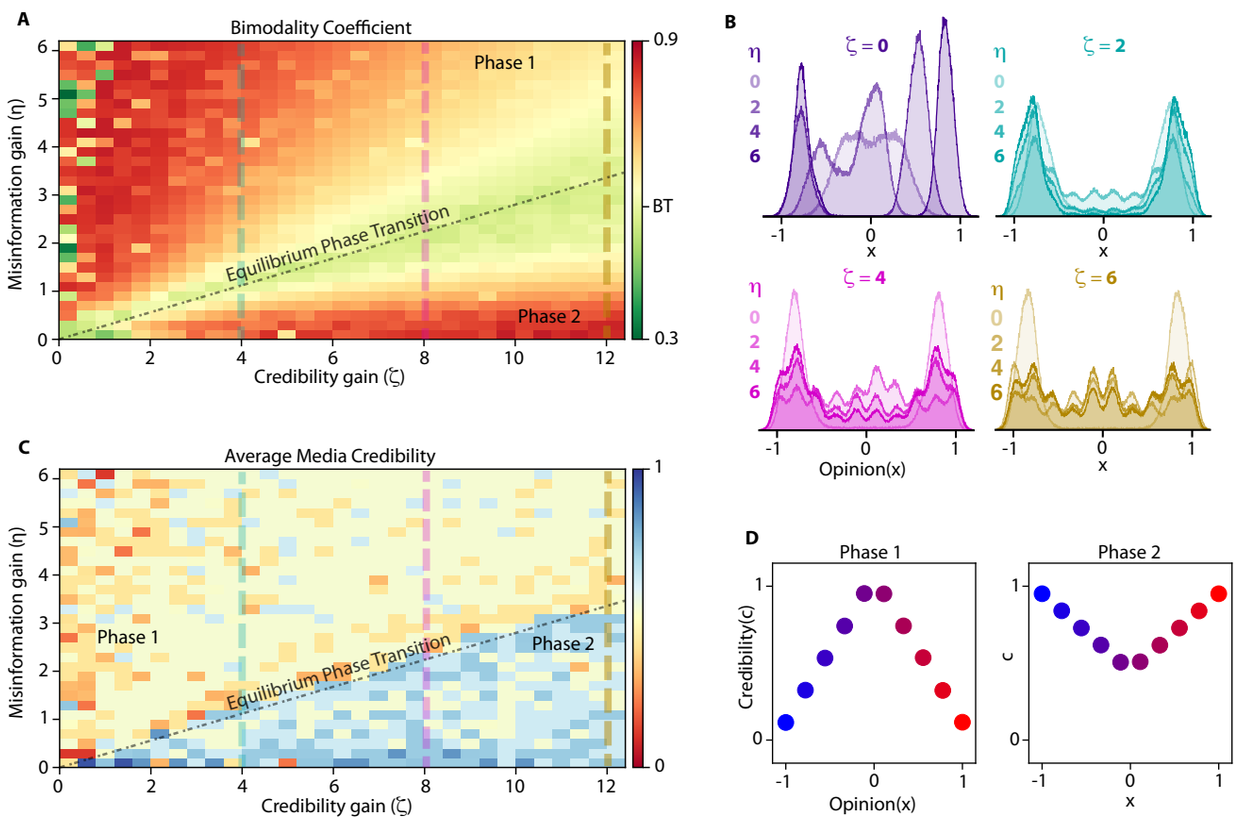


Sensitivity Analysis



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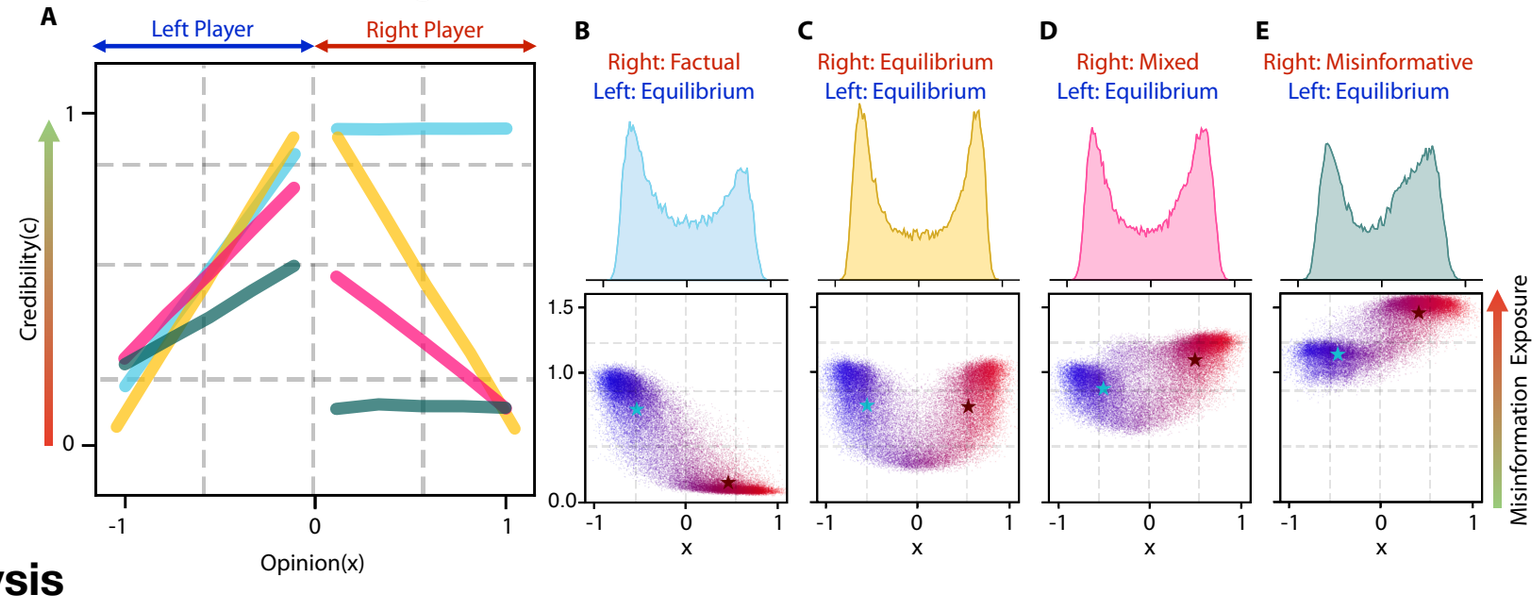

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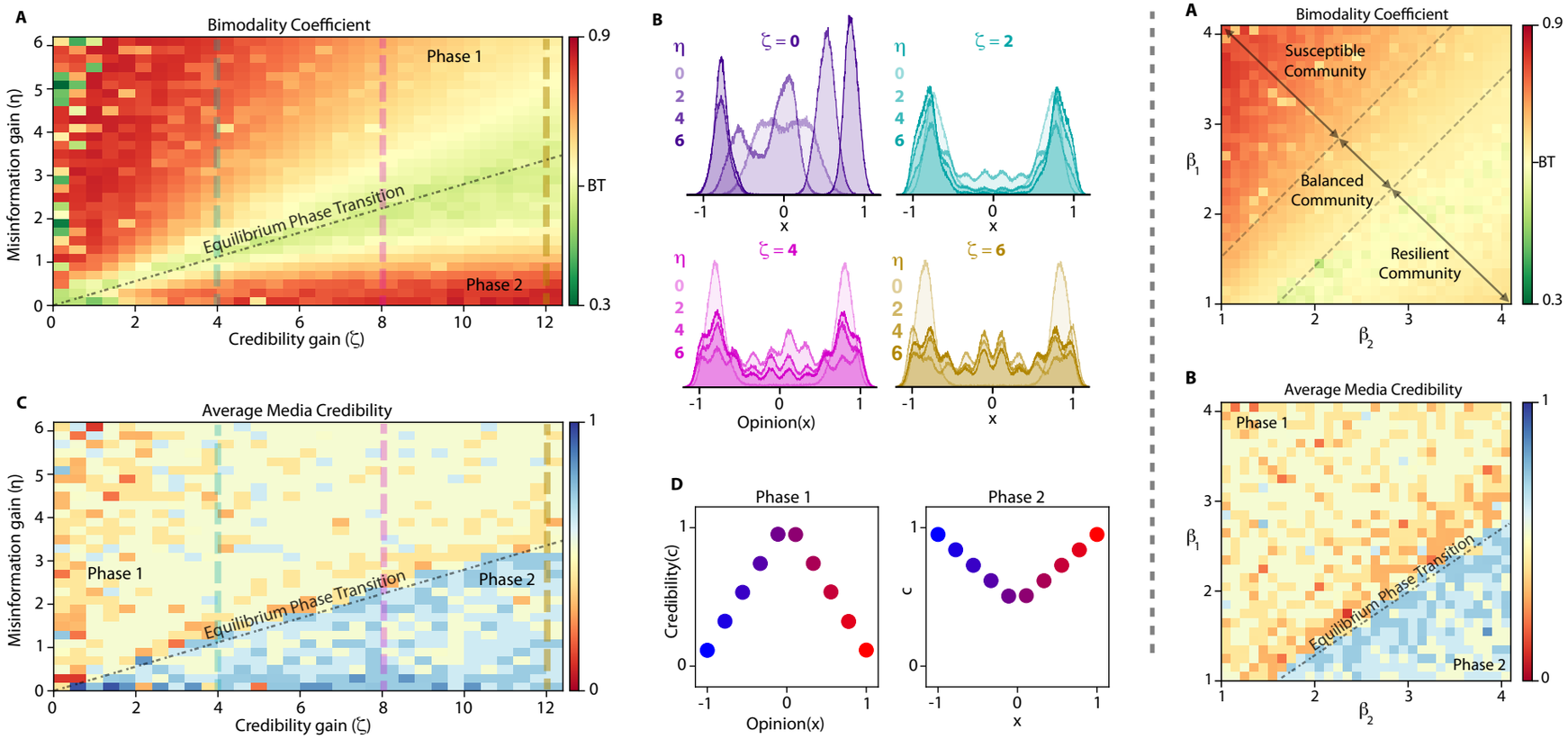

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Take Away

Misinformation Interventions

Misinformation Interventions

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Conclusion

- Misinformation is a *dynamic* problem.
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- The current information enviromen is *explotaible*

Countering Misinformation: Pre-bunking

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Points of intervention

[1] van der Linden, S. *Misinformation: susceptibility, spread, and interventions to immunize the public.* Nature Medicine, 2022

Countering Misinformation: Pre-bunking

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Points of intervention

Option 1: Debunking

Identify misinformed users.
Correct internalized misinformation by debunking their perceived beliefs.

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Countering Misinformation: Pre-bunking

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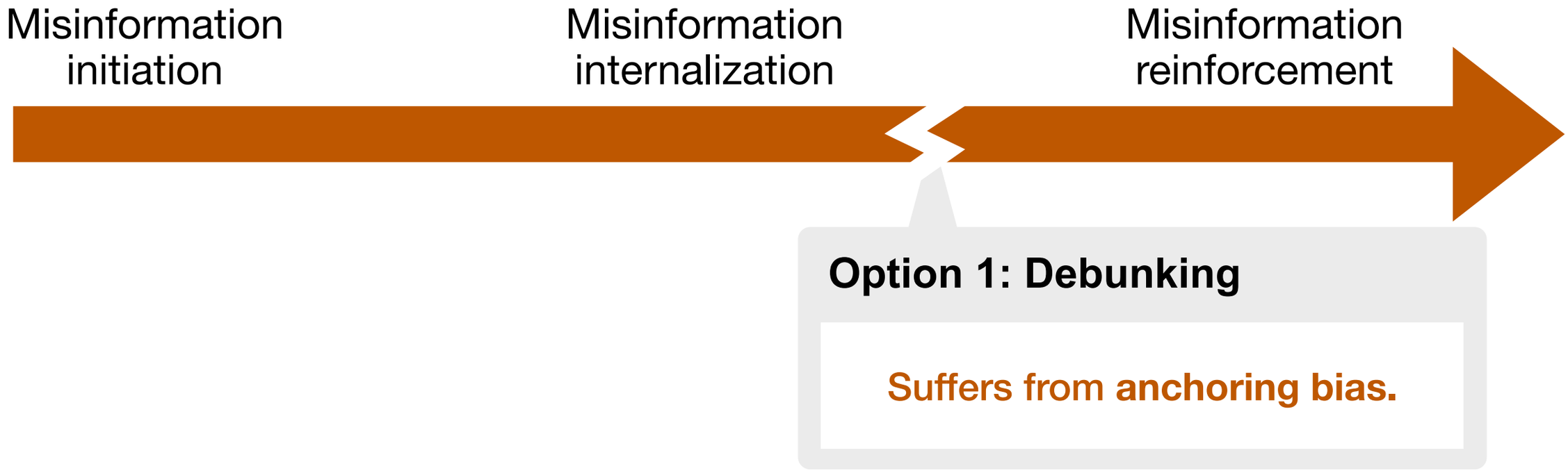
Points of intervention



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Countering Misinformation: Pre-bunking

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Points of intervention

Option 2: Pre-bunking

Identify at-risk users.

Educate users to be resilient to future misinformation cascades

Option 1: Debunking

Suffers from anchoring bias.

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Countering Misinformation: Pre-bunking

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Points of intervention

Misinformation initiation → Misinformation internalization → Misinformation reinforcement

Option 2: Pre-bunking

Identify at-risk users.

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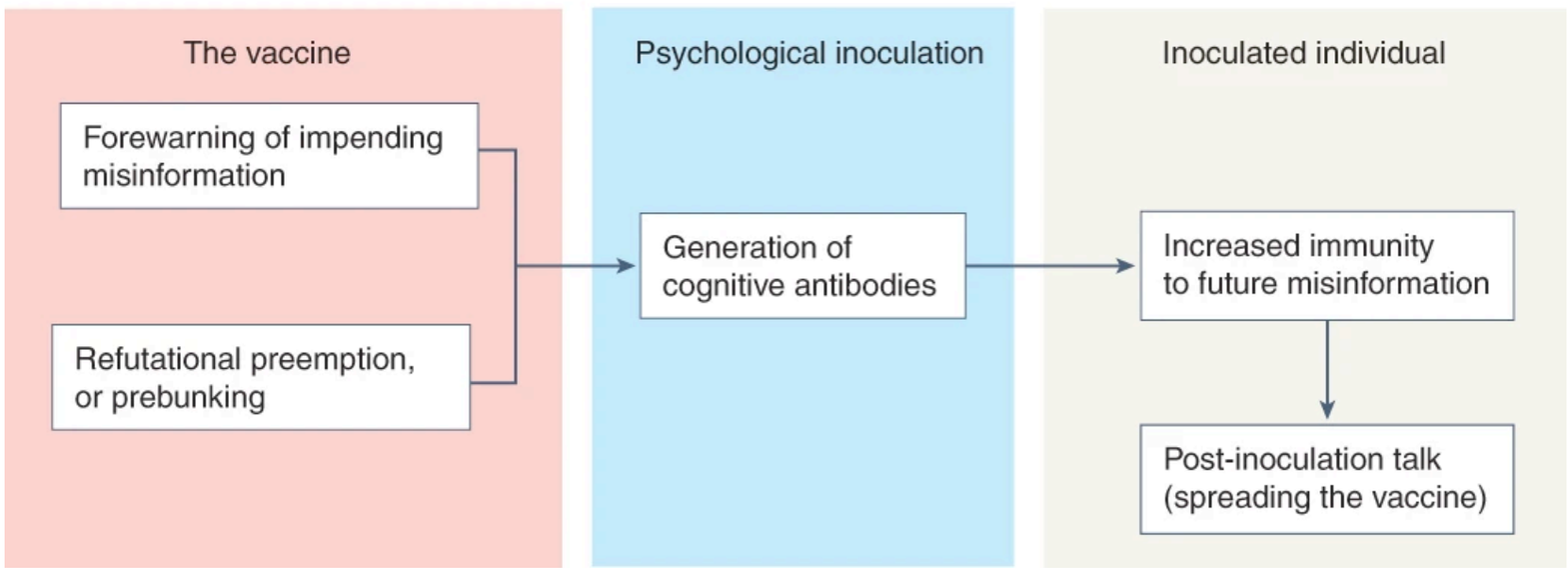
Option 1: Debunking

Suffers from anchoring bias.

Theory of psychological inoculation



Preemptively inoculating users with correct information immunizes them against misinformation[1].

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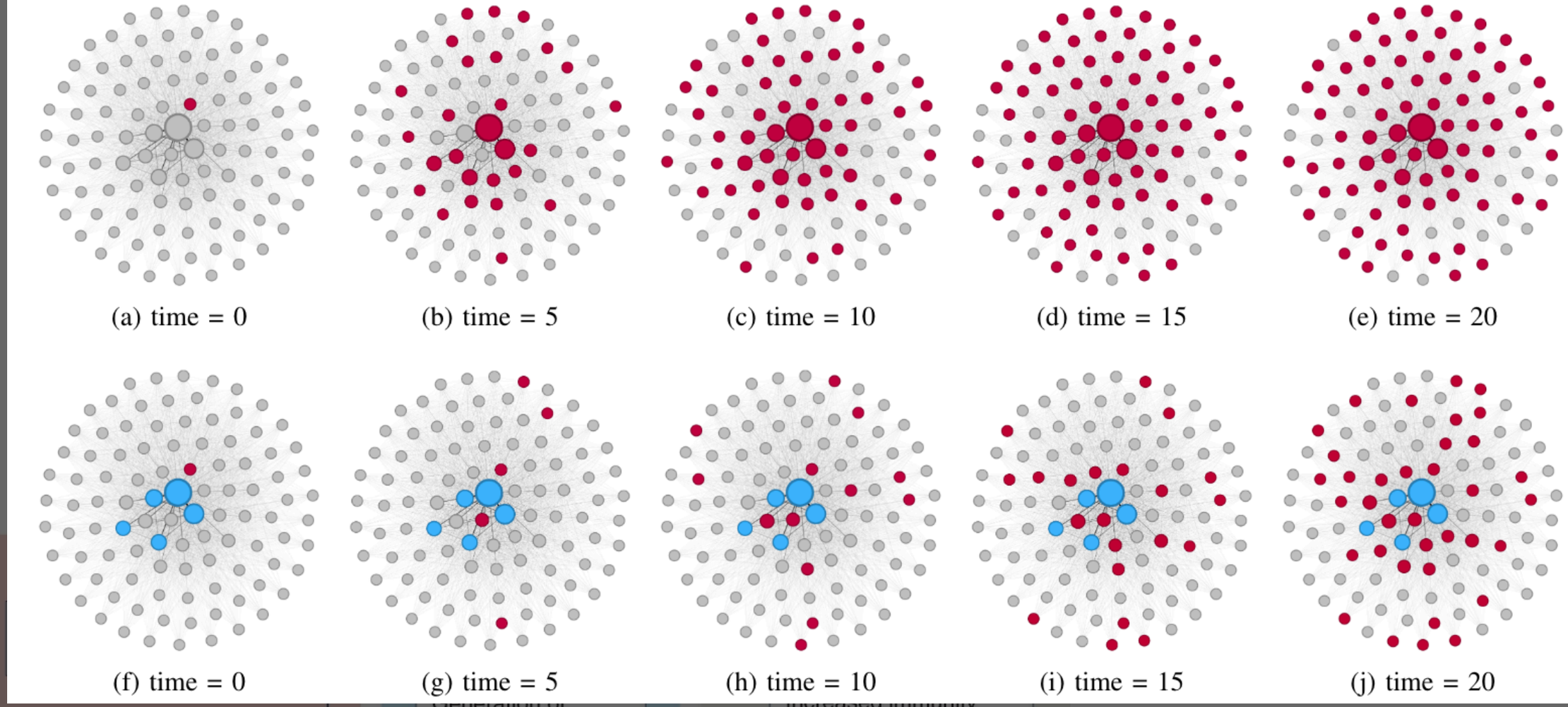

s with
s them

Refutational preemption, or prebunking

cognitive antibodies

to future misinformation

Post-inoculation talk (spreading the vaccine)

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Countering Misinformation: Pre-bunking

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When to Inoculate?

Overusing pre-bunking negatively affects user experience

[1] Y. E. Bayiz, U. Topcu, *Prebunking Design as a Defense Mechanism Against Misinformation Propagation on Social Networks,* Submitted to CDC 2025

Countering Misinformation: Pre-bunking

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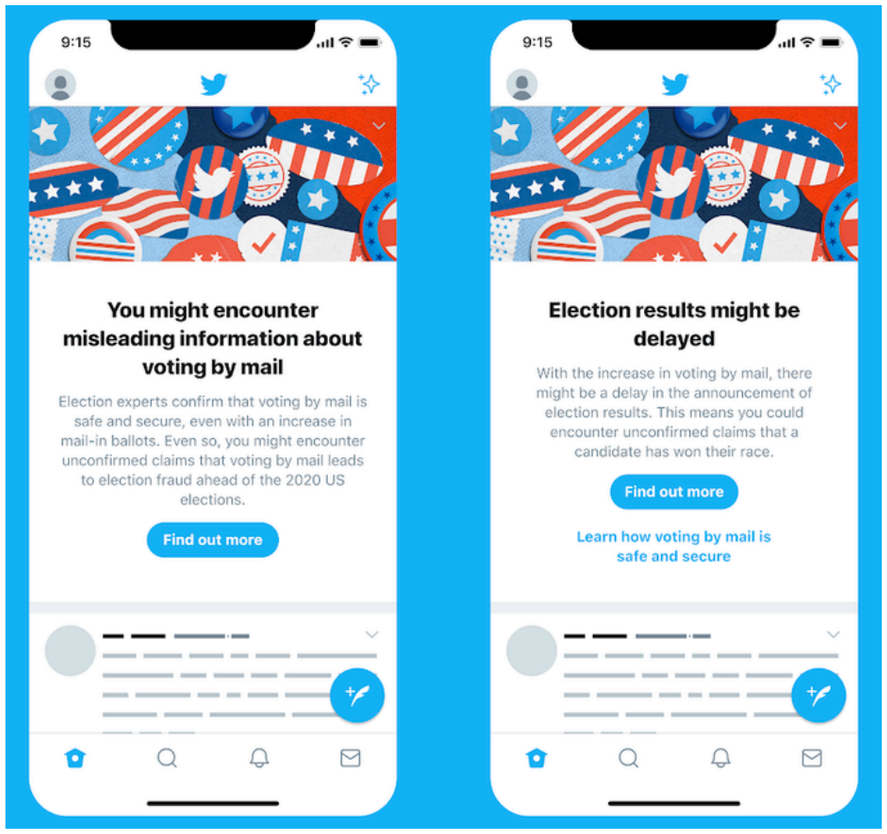

Overusing pre-bunking negatively affects user experience

Content Sequence: $Q = q_1, q_2, q_3, \dots$

Misinformation Misc. Content

$q_i \in \mathbf{M} \cup \mathbf{P} \cup \mathbf{C}$

Pre-bunk

Example:

$$Q = C_1, C_2, C_1, M_1, C_2, M_2, C_4, \dots$$

Multiple misinformation sources

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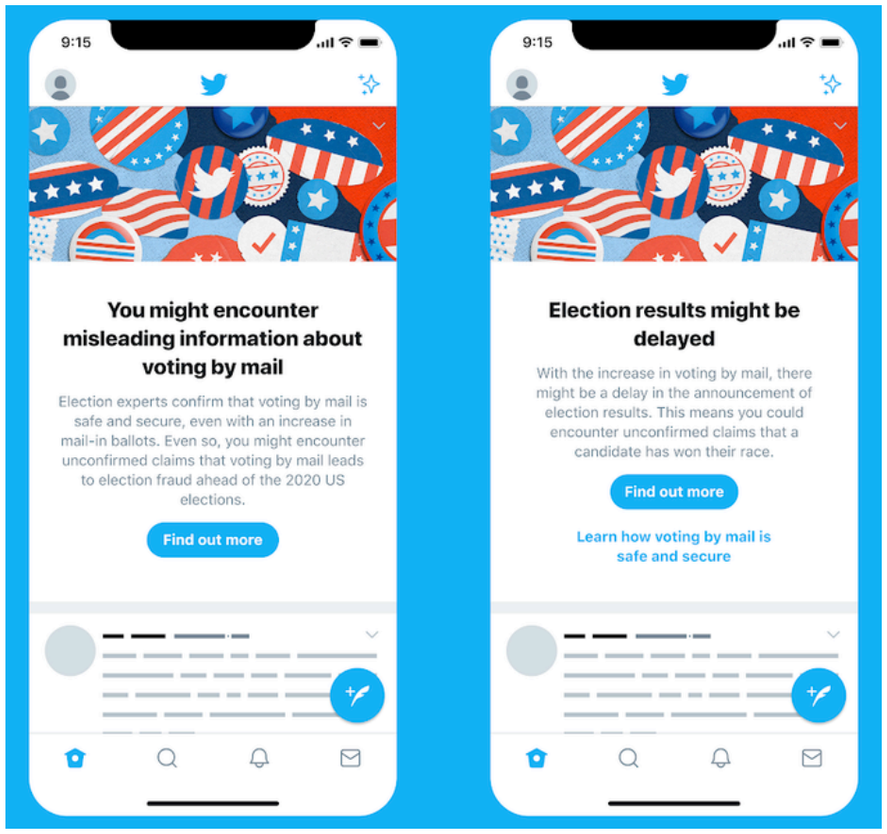

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Multiple misinformation sources

Goal 1: Ensure pre-bunks are delivered before misinformation. Eg: $C_1, P_1, C_2, C_1, M_1, C_2, P_2, M_2, C_4, \dots$

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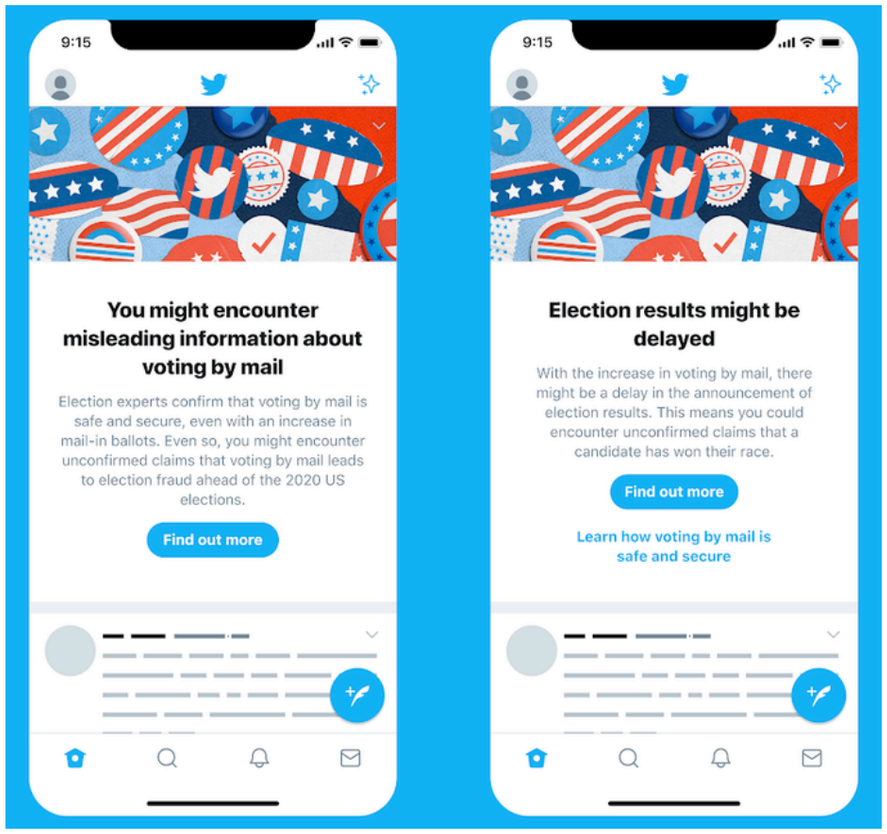

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Eg: $C_1, P_1, C_2, C_1, M_1, C_2, P_2, M_2, C_4, \dots$

Goal 2: Minimize pre-bunk concentration in feed.

$$\min_{a} \max_{i} c_{i+1} = \beta c_i + \mathbf{1}_{\{q_i \in \mathbf{P}\}}$$

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Countering Misinformation: Pre-bunking

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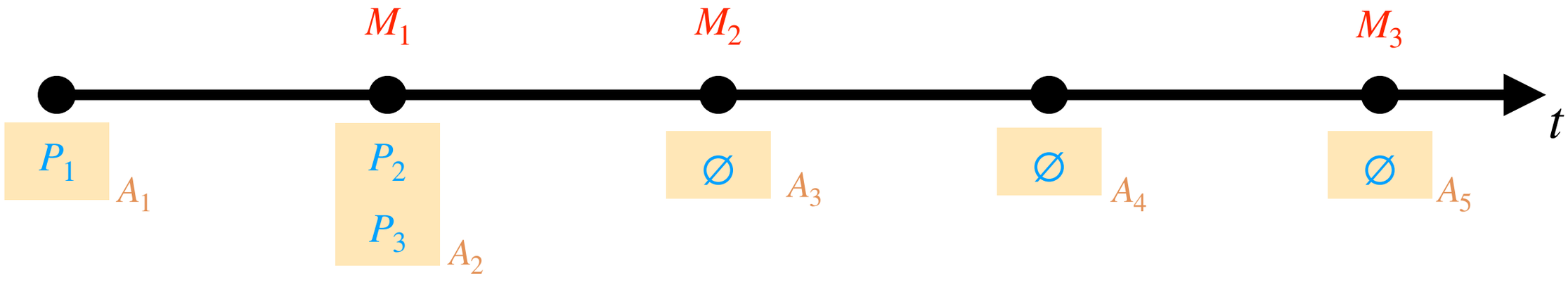
Each M_i propagates based on an **SI** epidemic model.

At each time we can decide on which pre-bunks to deliver based on policy $\pi(I_t^1, \ldots I_t^k)$.



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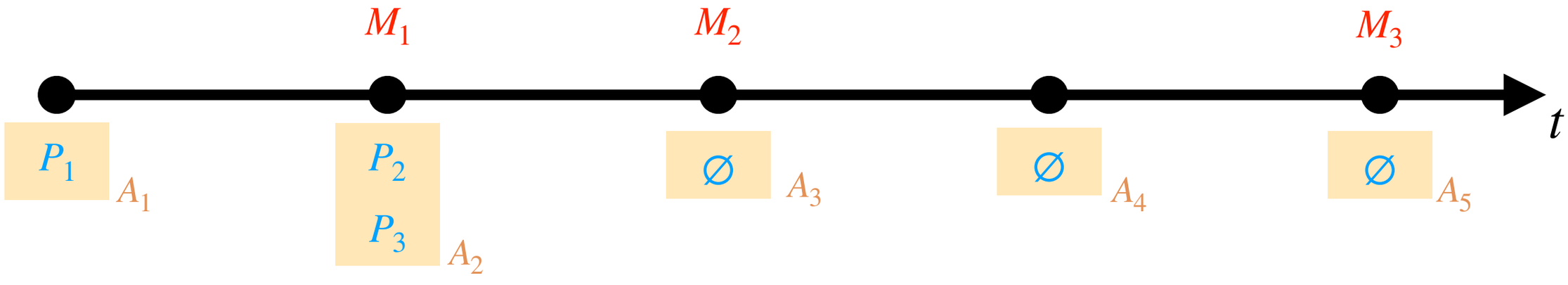

$$\min_{\pi \in \Pi} \max_{t \in [T]} \quad c(\pi, t)$$

$$\text{s.t.} \quad A_1, \ldots, A_T \sim \pi\left(I_t^1 \ldots I_t^k\right),$$

$$\forall k \in \mathbb{N}, \quad \mathbb{P}\left(P_k \in \bigcup_{t=0}^{X_k - 1} A_t\right) = 1.$$

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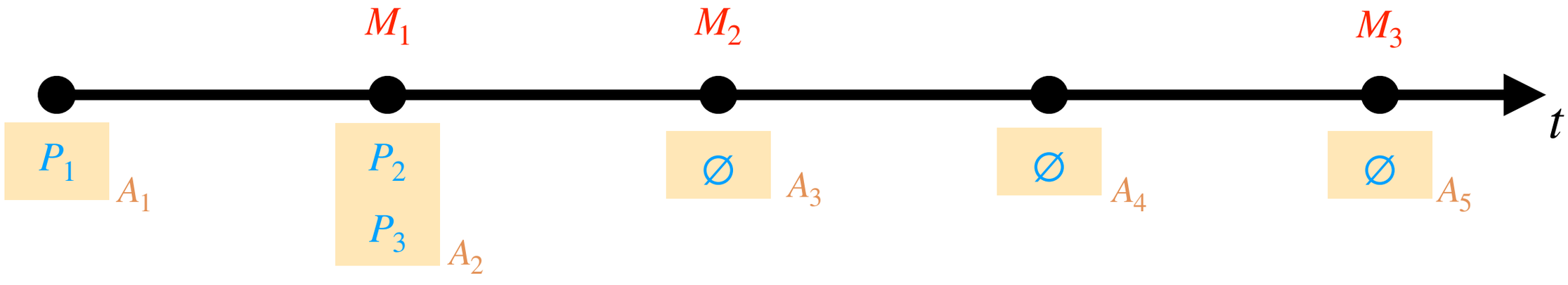

$$\min_{\pi\in\Pi} \max_{t\in[T]} \quad c(\pi, t) \longrightarrow c(\pi, t) = \sum_{\tau=1}^{t} \beta^{t-\tau} \mathbb{E}_\pi \left[\left| A_\tau \right| \right]$$

$$\text{s.t.} \quad A_1, \dots, A_T \sim \pi\left(I_t^1 \dots I_t^k\right), \longrightarrow \pi \text{ determines the actions } A_t.$$

$$\forall k \in \mathbb{N}, \quad \mathbb{P}\left(P_k \in \bigcup_{t=0}^{X_k - 1} A_t \right) = 1. \longrightarrow \text{Deliver pre-bunks before misinformation}$$

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Two Baseline Policies

We want to ensure $\forall k \in \mathbb{N}, \quad \mathbb{P}\left(P_k \in \bigcup_{t=0}^{X_k - 1} A_t \right) = 1.$

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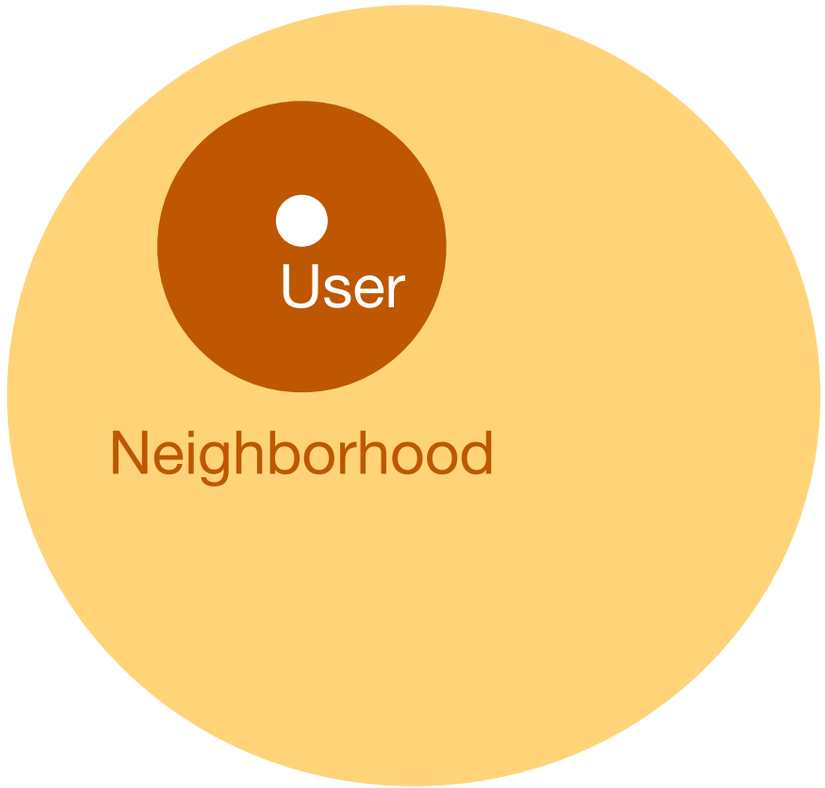

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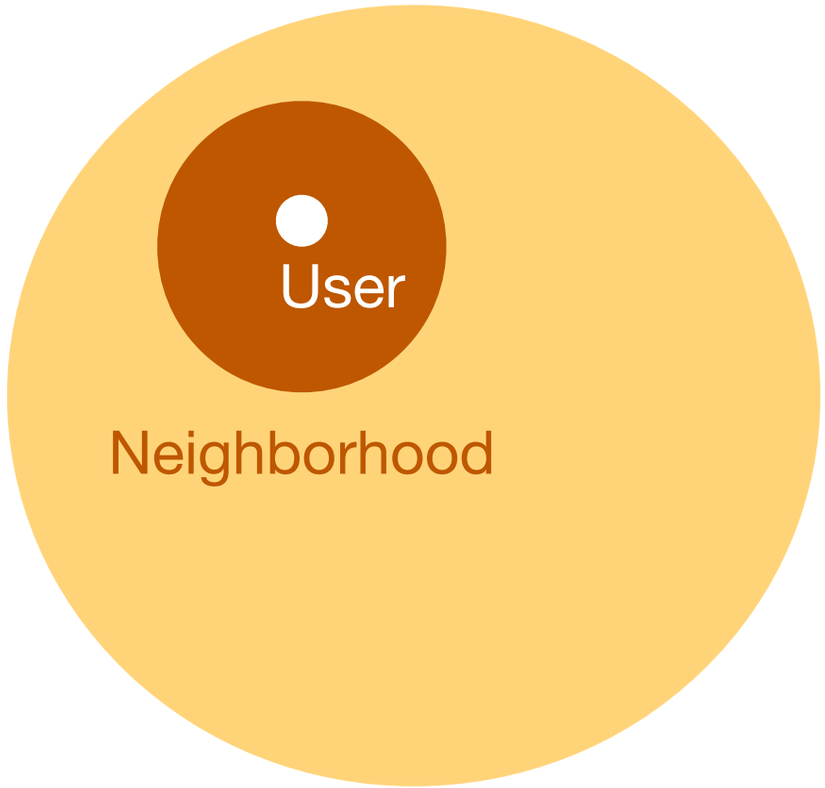

Both policies yield feasible but suboptimal solutions.

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Equal Pre-bunk Spacing

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Proxy Problem

Optimally deliver $\lfloor \epsilon T \rfloor$ pre-bunks until time T.

$$\min_{t_1 \dots t_{\lfloor \epsilon T \rfloor}} \max_{n \in \{0 \dots \lfloor \epsilon T \rfloor\}} \sum_{i=1}^{n} \beta^{t_n - t_j},$$

$$\text{s.t.} \quad 0 \leq t_{i-1} \leq t_i \leq T, \quad \forall i \in \{1 \dots \lfloor \epsilon T \rfloor\}.$$

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Theorem: Let $t_0 \dots t_{\lfloor \in T \rfloor} \in \mathbb{R}$ be an optimal solution to above problem , then there exists h such that $t_i - t_{i-1}$ is constant across all $i = h+1, \dots, \lfloor \epsilon T \rfloor$. Specifically there exists a constant α such that[1],

$$t_h - t_{h-1} = \log_\beta(\alpha - 1) - \log_\beta(h),$$
$$t_i - t_{i-1} = \log_\beta(\alpha - 1) - \log_\beta(\alpha).$$

[1] Y. E. Bayiz, U. Topcu, *Prebunking Design as a Defense Mechanism Against Misinformation Propagation on Social Networks,* Submitted to CDC 2025

Equal Pre-bunk Spacing

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Proxy Problem

Optimally deliver $\lfloor \epsilon T \rfloor$ pre-bunks until time T.

$$\min_{t_1 \dots t_{\lfloor \in T \rfloor}} \max_{n \in \{0 \dots \lfloor \epsilon T \rfloor\}} \sum_{i=1}^{n} \beta^{t_n - t_j},$$
$$\text{s.t.} \quad 0 \le t_{i-1} \le t_i \le T, \quad \forall i \in \{1 \dots \lfloor \epsilon T \rfloor\}.$$

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Optimal solution of the proxy problem evenly distributes pre-bunks.

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Re-ranking for Credibility

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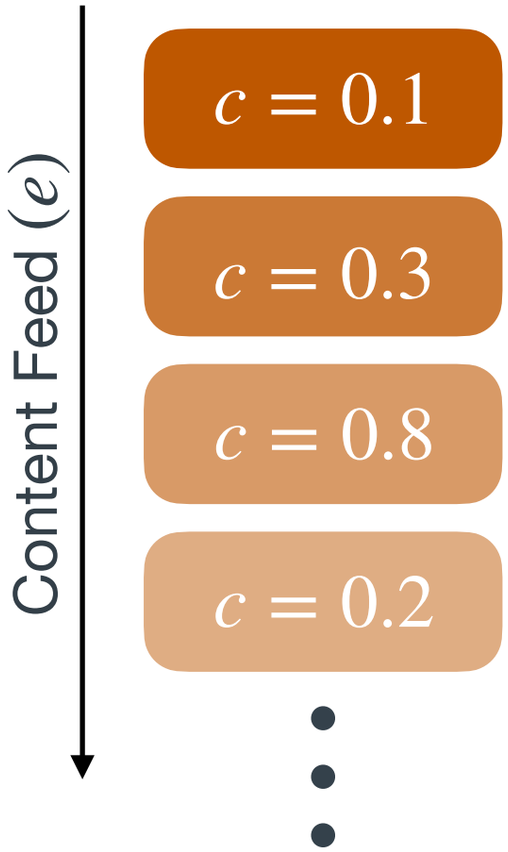
Assumption: Content arrives already sorted in a **content feed** based on original value assignment $V(\sigma)$



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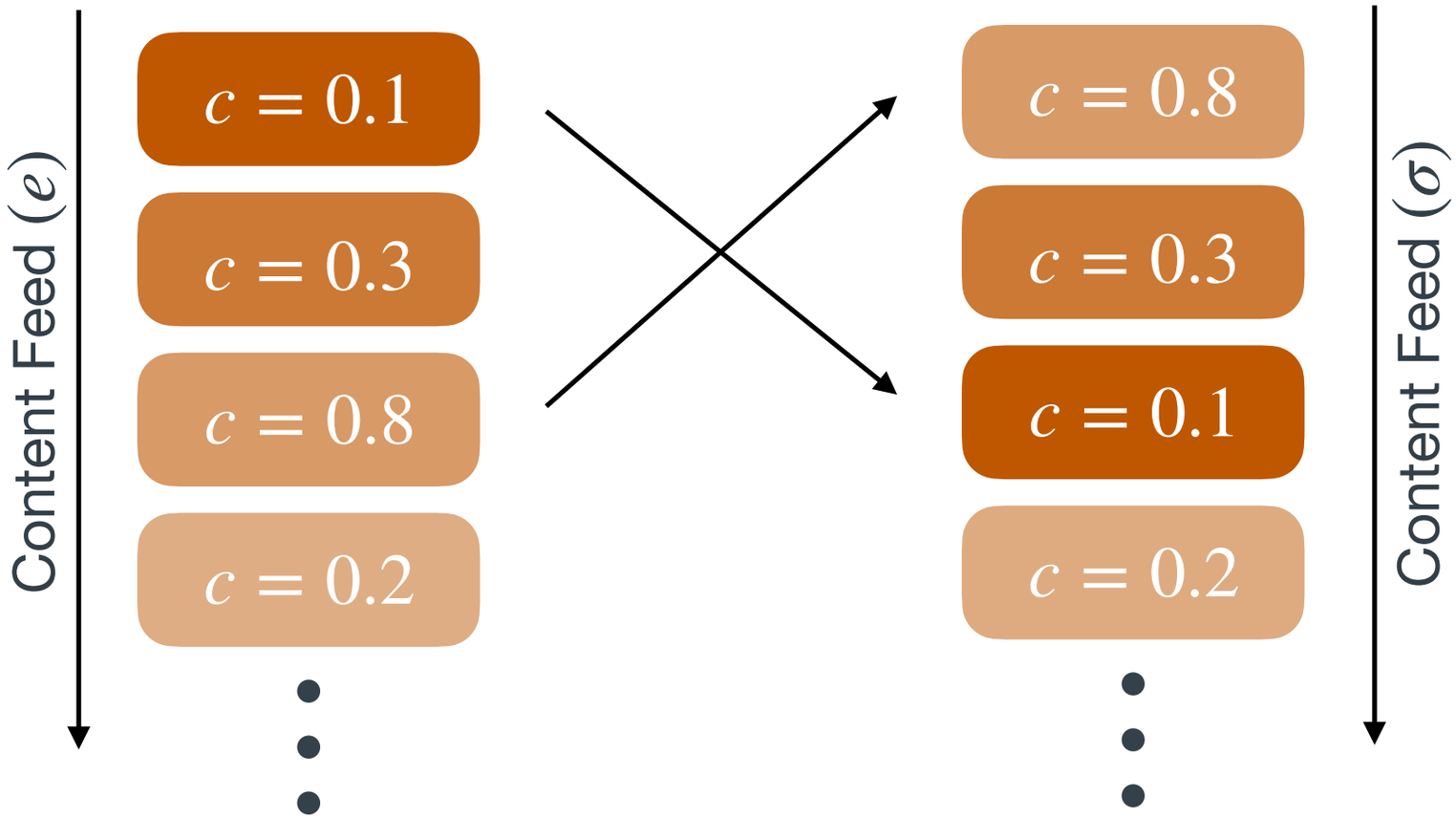

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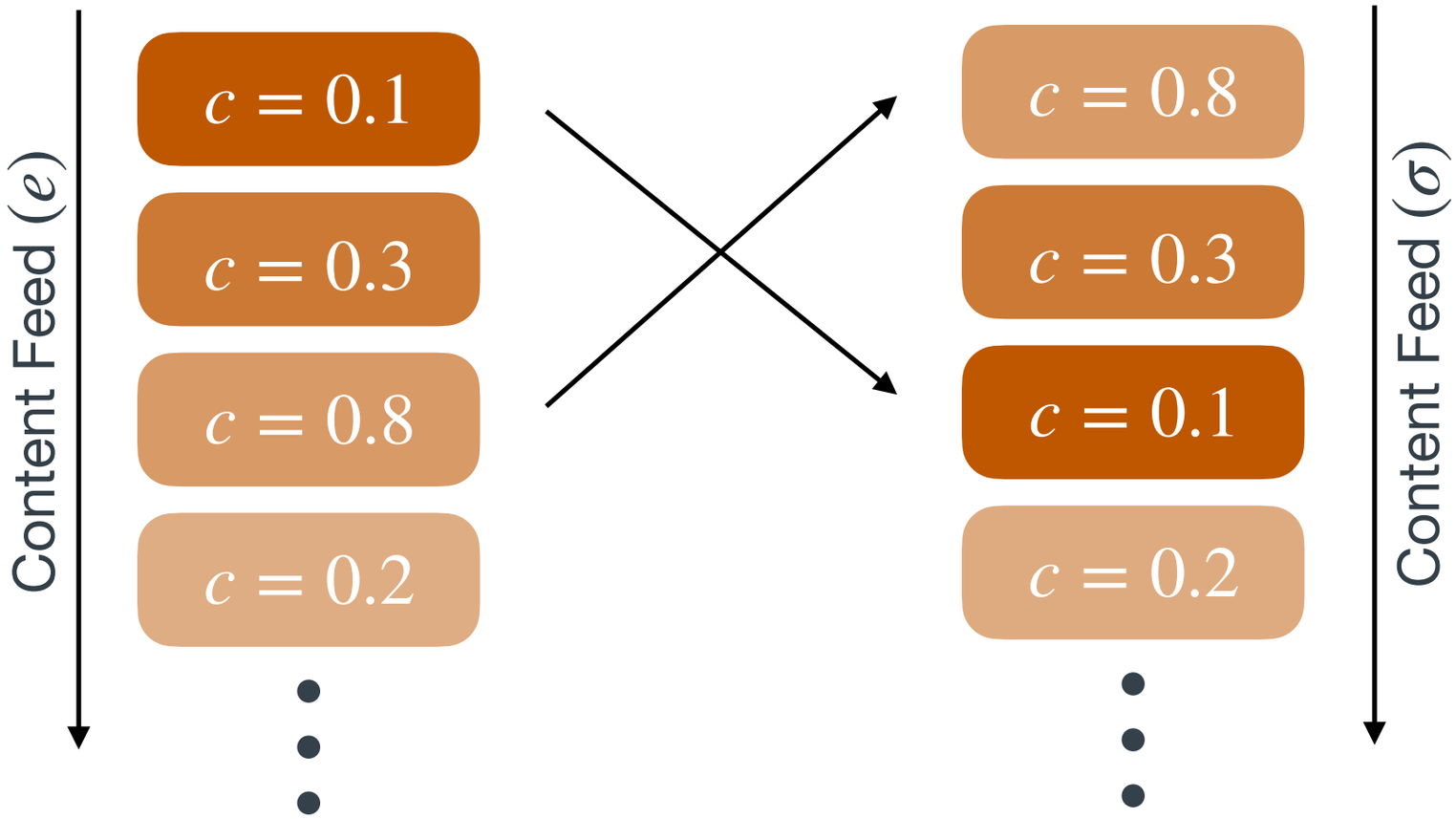

Assume that user sees p^{th} post with probability

$$q_p = \lambda^p \longrightarrow \textbf{persistence}$$

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Re-ranking for Credibility

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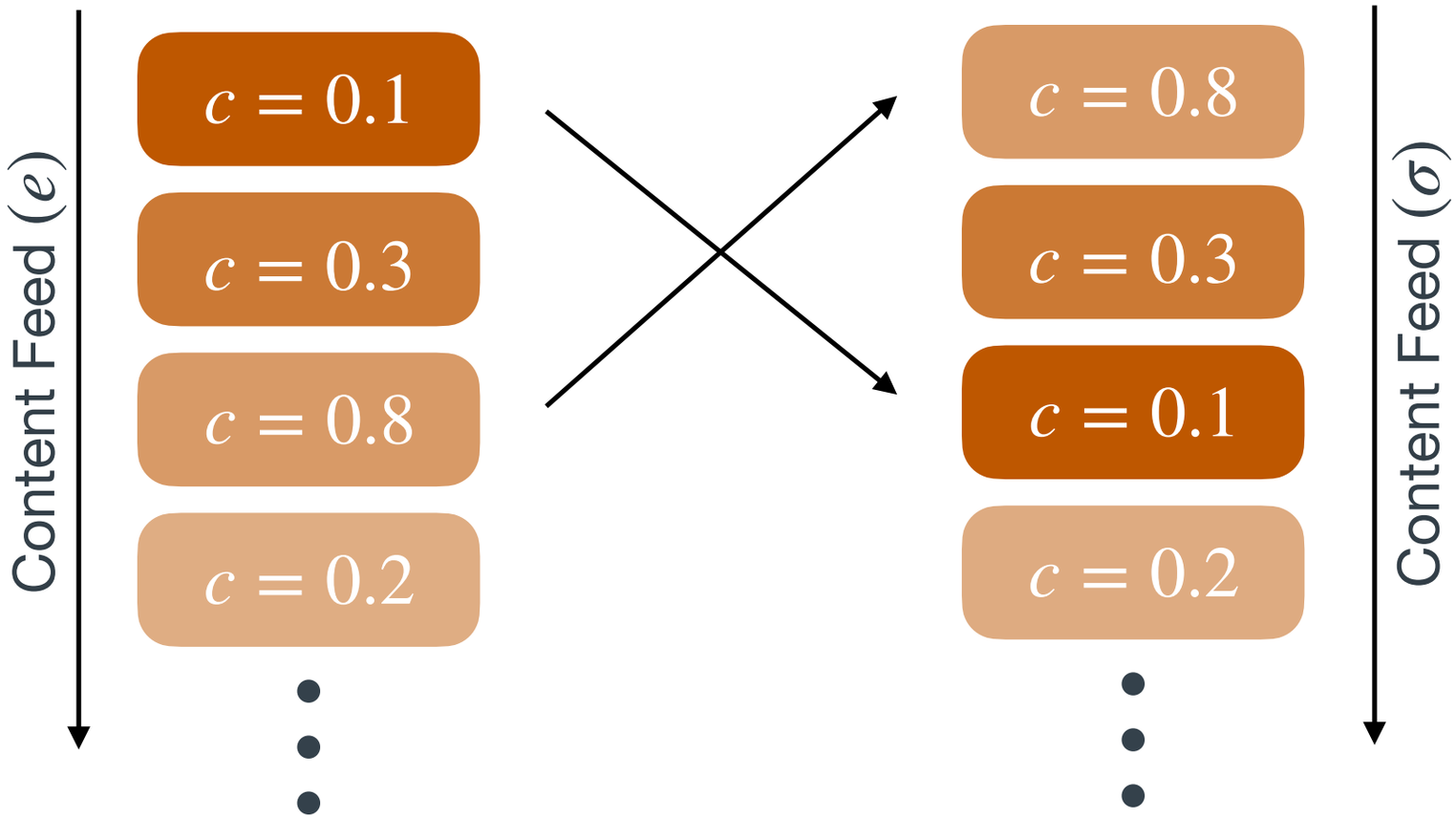
Identity permutation optimizes platform objectives



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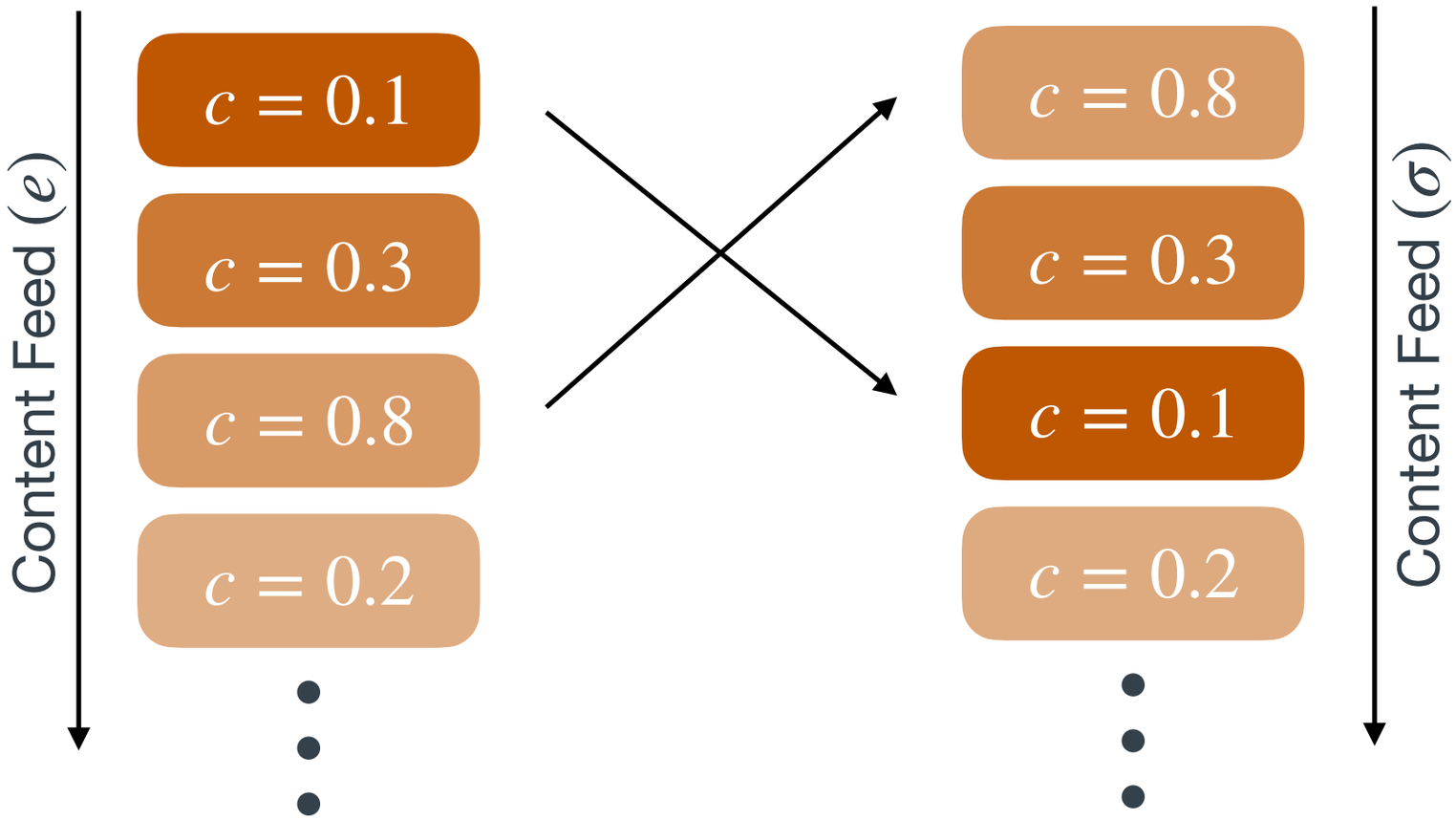

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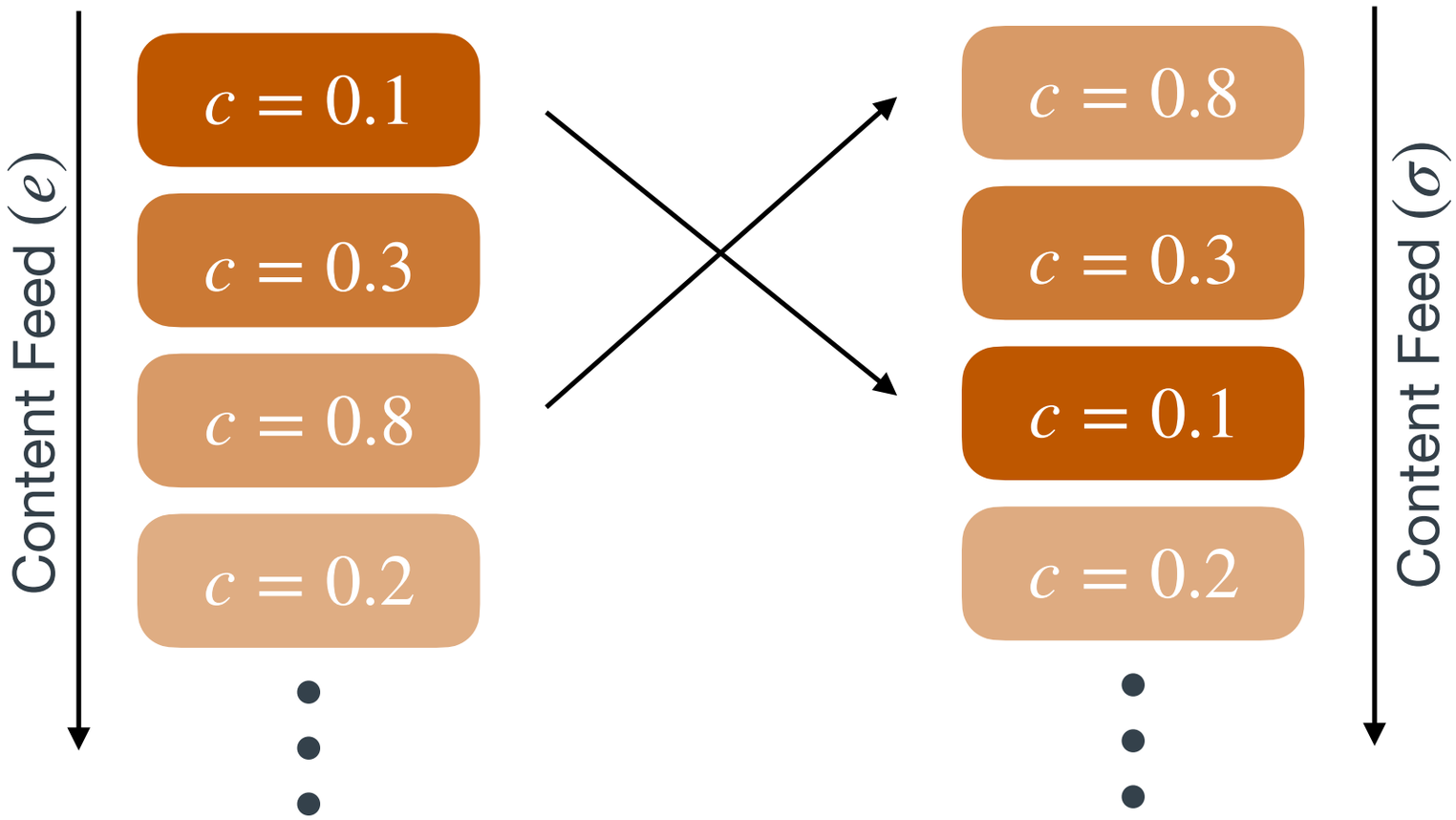

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Problem: $V(\sigma)$ is not known

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Re-ranking for Credibility

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Misinformation is vaguely defined.

- Fake News
- Propaganda
- Scams
- Rumors

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Democratic View

Suppose a randomly selected user labels post p as $Z_p \sim \text{Bernoulli}(c)$

Define credibility as $E[Z_p] = c$

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Parse top k news articles

Determine credibility based on the consensus

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We use a hybrid approach that utilizes both views.

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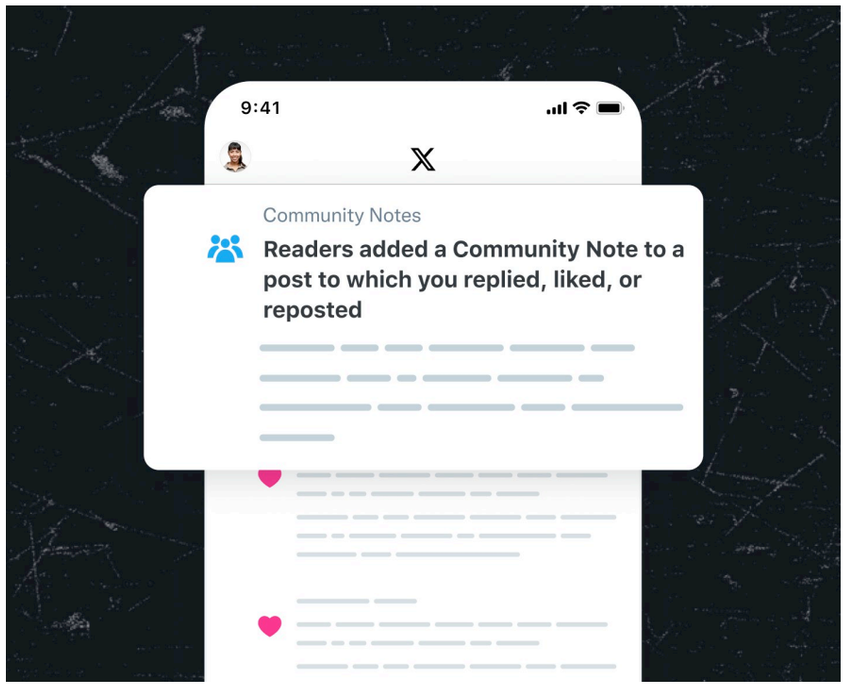
Community Notes



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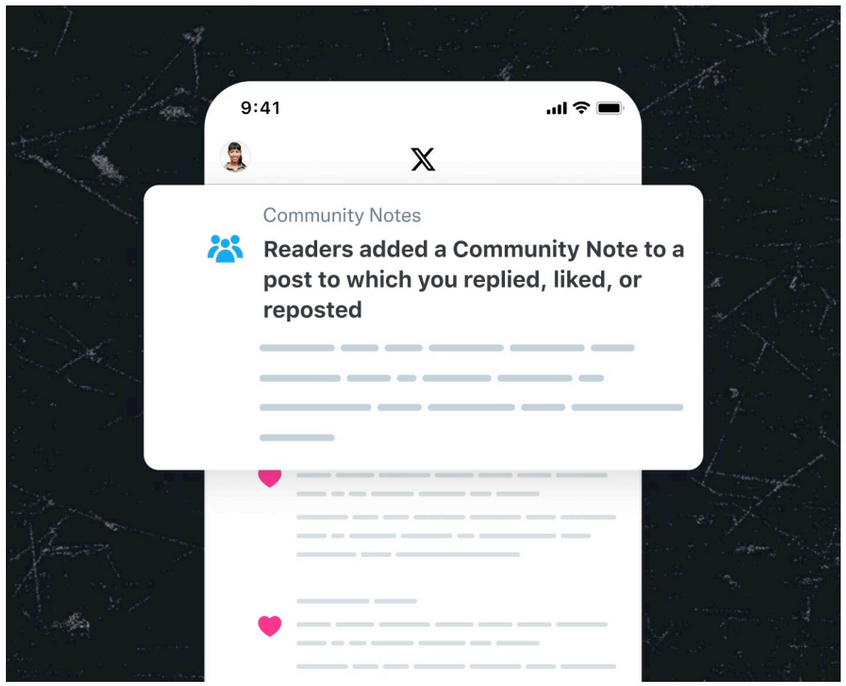

$$\hat{c}_p^{\text{human}} = \frac{\sum_{i=1}^{n} \left(z_{p,i} \cdot h_{p,i}^{+} + (1 - z_{p,i}) \cdot h_{p,i}^{-} \right)}{\sum_{i=1}^{n} \left(h_{p,i}^{+} + h_{p,i}^{-} \right)},$$

- Each post p comes with community notes
- Each community note i comes with a verdict $z_{p,i}$
- Eat community note also comes with ratings:
  - $h_{p,i}^{+}$: Number of ‘helpful’ ratings
  - $h_{p,i}^{-}$: Number of ‘not helpful’ ratings

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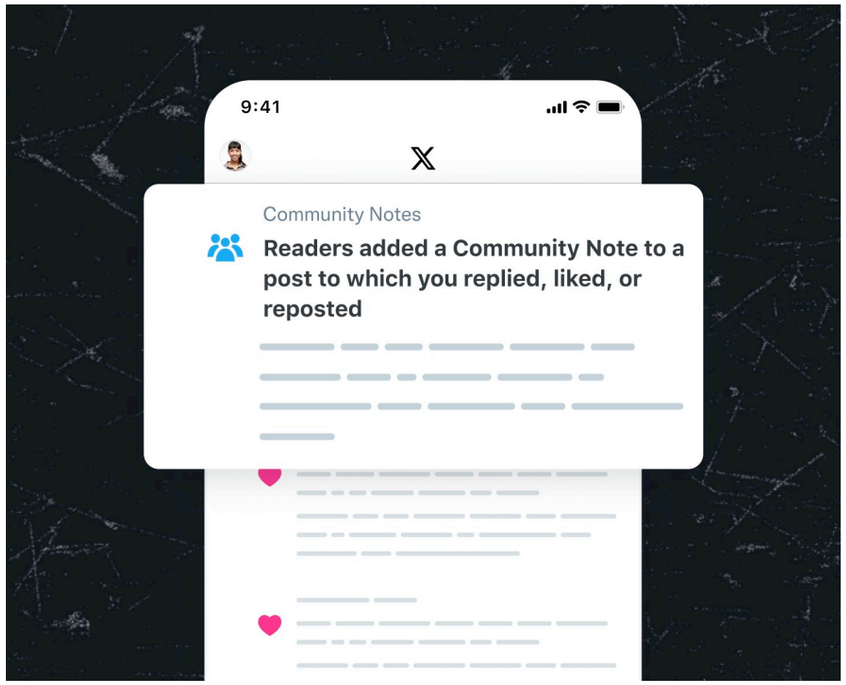

Push towards note verdict if helpful

Push away from note verdict if not helpful

$$\hat{c}_p^{\text{human}} = \frac{\sum_{i=1}^{n} \left(z_{p,i} \cdot h_{p,i}^{+} \right) + \left((1 - z_{p,i}) \cdot h_{p,i}^{-} \right)}{\sum_{i=1}^{n} \left(h_{p,i}^{+} + h_{p,i}^{-} \right)},$$

Total number of ratings across all posts

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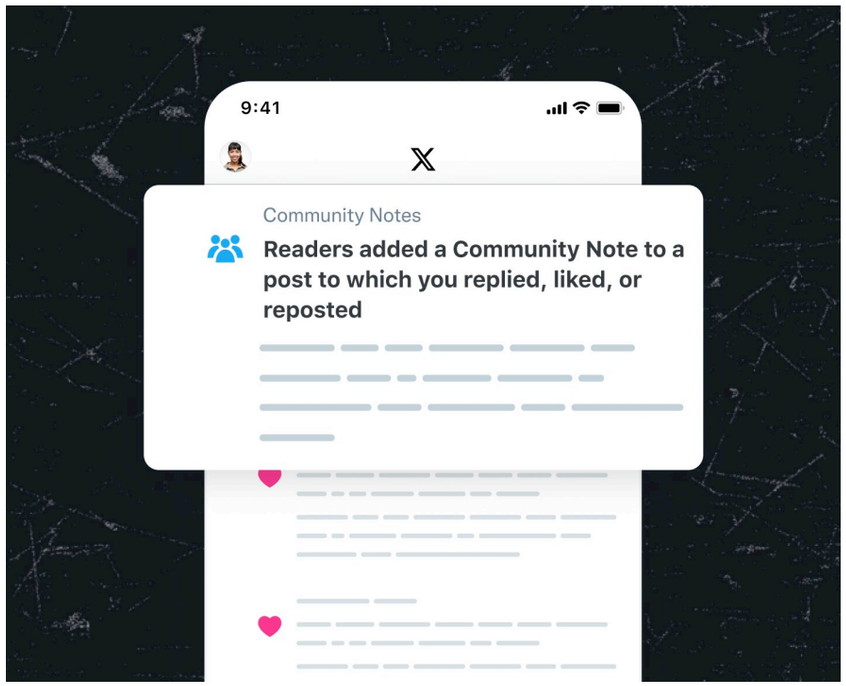

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$$\hat{c}_p^{\text{human}} = \frac{\sum_{i=1}^{n} \left(z_{p,i} \cdot h^{+}_{p,i} \right) + \left((1 - z_{p,i}) \cdot h^{-}_{p,i} \right)}{\sum_{i=1}^{n} \left(h^{+}_{p,i} + h^{-}_{p,i} \right)},$$

Total number of ratings across all posts

Assuming ratings and notes come from uniformly sampled users

$\hat{c}_p^{\text{human}}$ is an unbiased estimator of $c = E[Z_p]$

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Enhancing Human Scores

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Generate artificial community notes using retrieval augmented generation (RAG)

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Enhancing Human Scores

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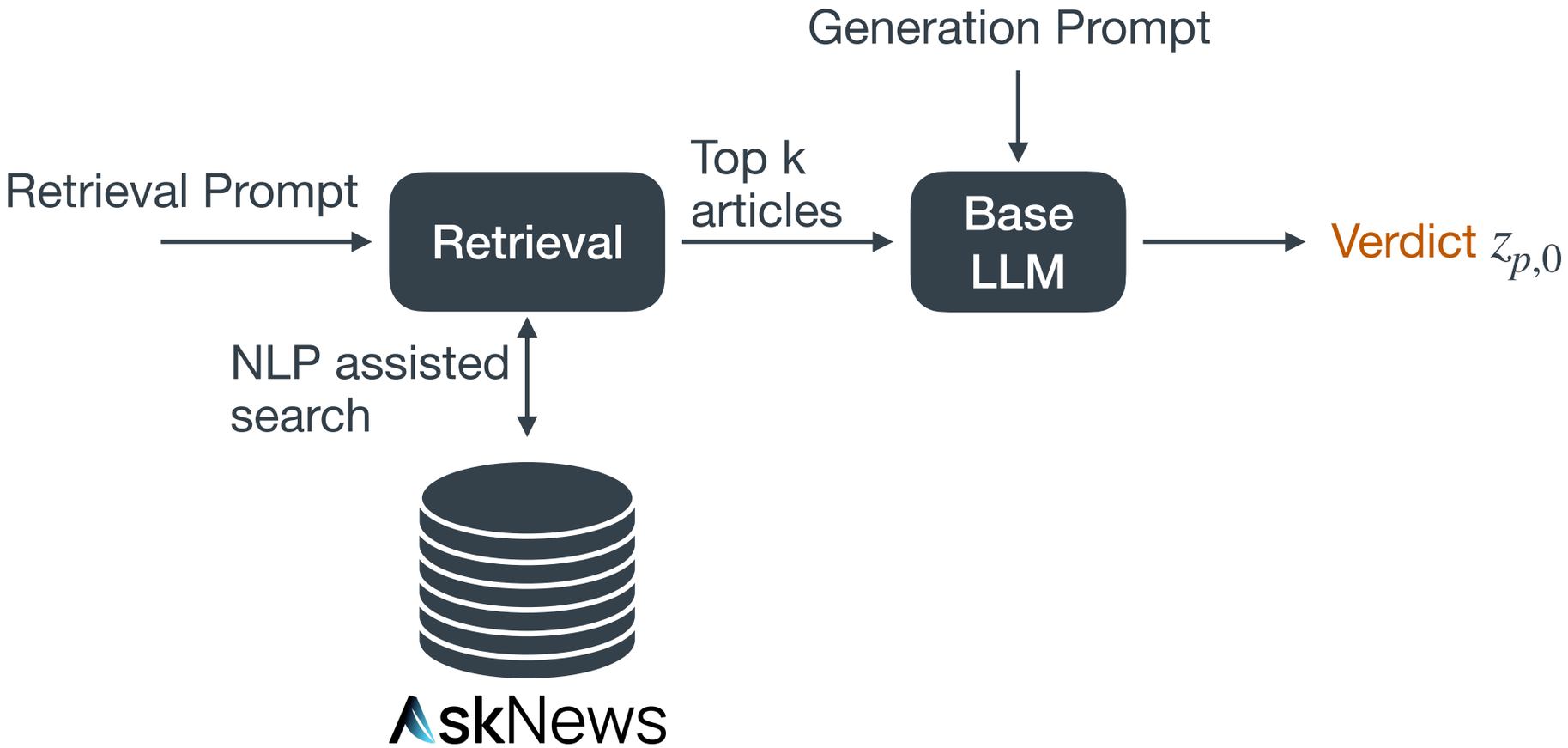

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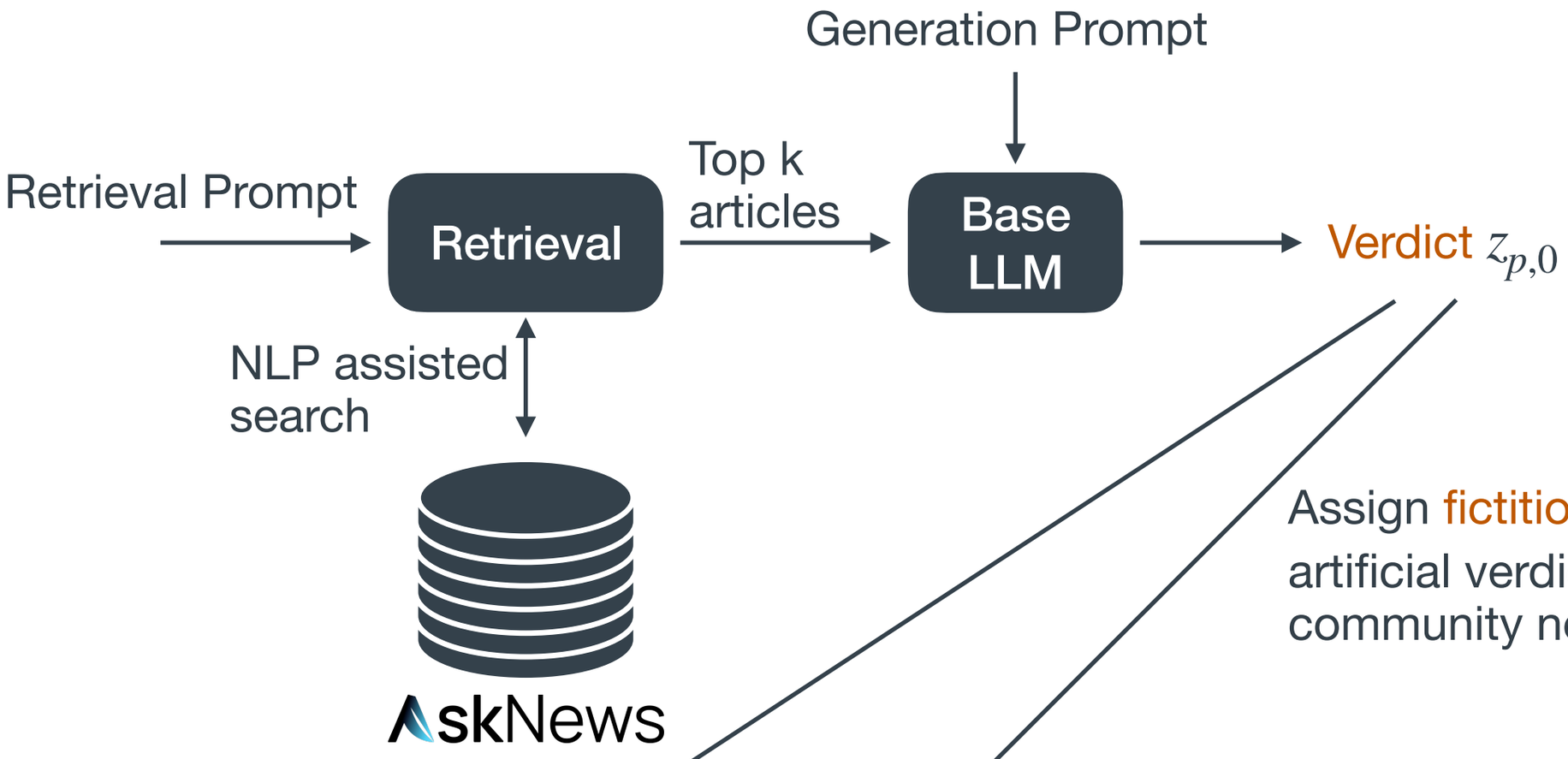

$$\hat{c}_p = \frac{z_{p,0} \cdot k^+ + (1 - z_{p,0}) \cdot k^- + \sum_{i=1}^{n} \left(z_{p,i} \cdot h_{p,i}^+ + (1 - z_{p,i}) \cdot h_{p,i}^- \right)}{\sum_{i=1}^{n} \left(h_{p,i}^+ + h_{p,i}^- \right) + k^+ + k^-}$$

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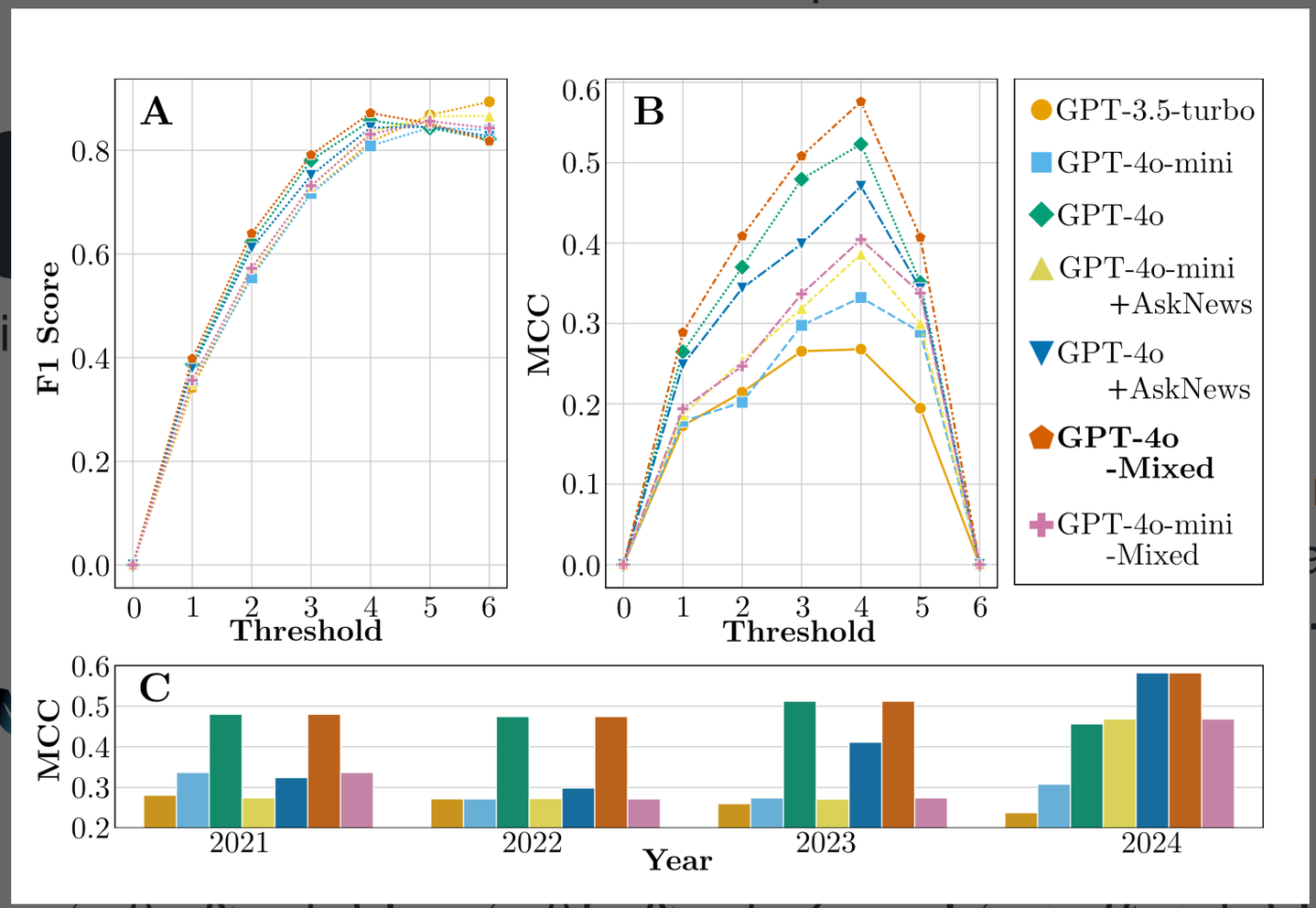
Retrieval Prompt

NLP assi
search

Generation Prompt



ratings k_p^+, k_p^- to
and treat it like a

$$\hat{c}_p = \frac{z_{p,0} \cdot k^+ + (1 - z_{p,0}) \cdot k^- + \sum_{i=1} \left(z_{p,i} \cdot h_{p,i}^+ + (1 - z_{p,i}) \cdot h_{p,i}^- \right)}{\sum_{i=1}^{n} \left(h_{p,i}^+ + h_{p,i}^- \right) + k^+ + k^-}$$

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Re-ranking for Credibility

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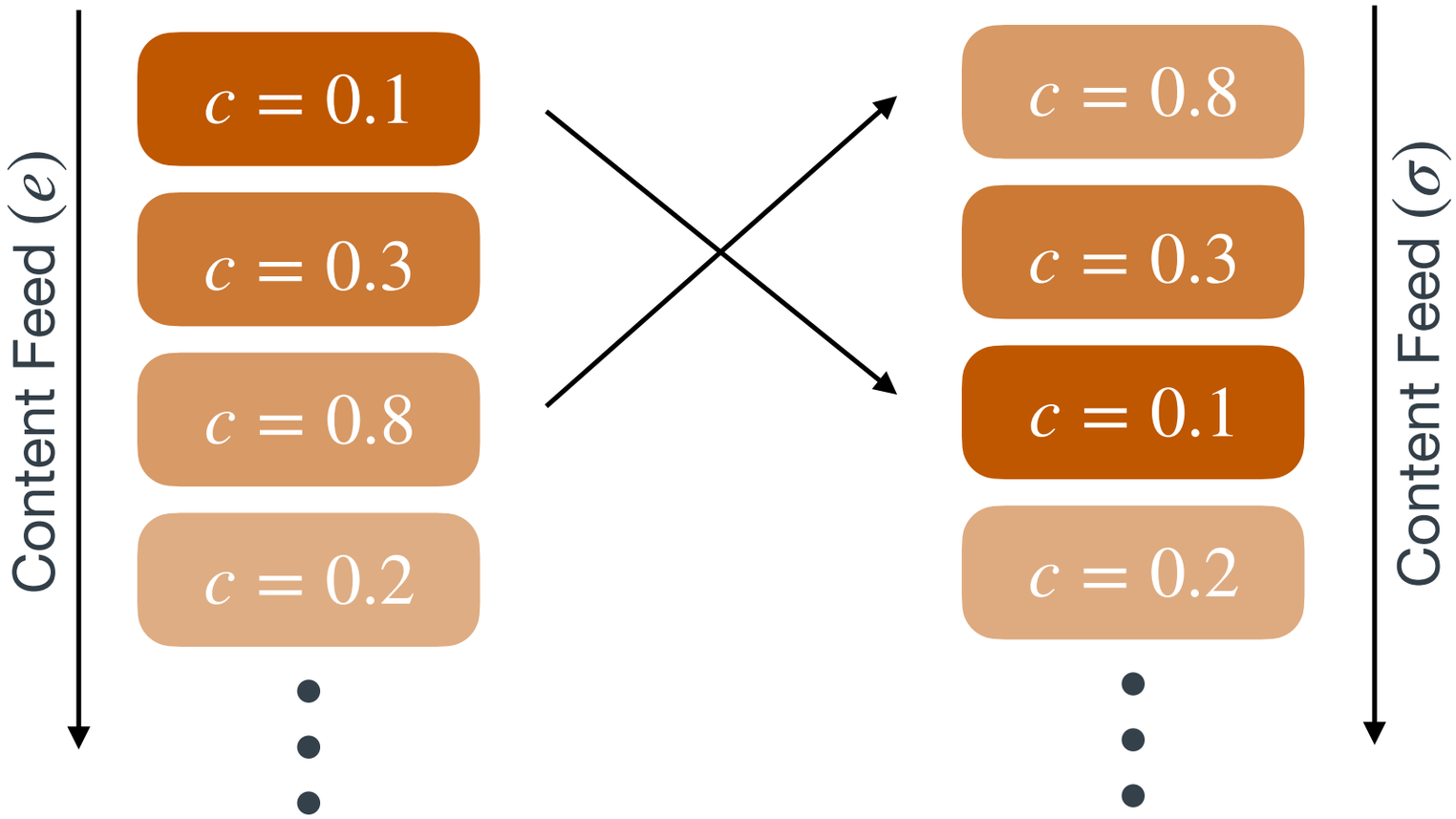

$$\max_{\sigma \in S_K} \quad \alpha V(\sigma) + \sum_{p=1}^{K} q_p c_{\sigma(p)}$$

Problem: $V(\sigma)$ is not known

($V(\sigma)$ may not even exist)

Assume identity permutation optimizes platform objectives

$$e = \arg\max_{\sigma} V(\sigma) \qquad V(\sigma) = \sum_{p=1}^{K} q_p v(\sigma(p)),$$

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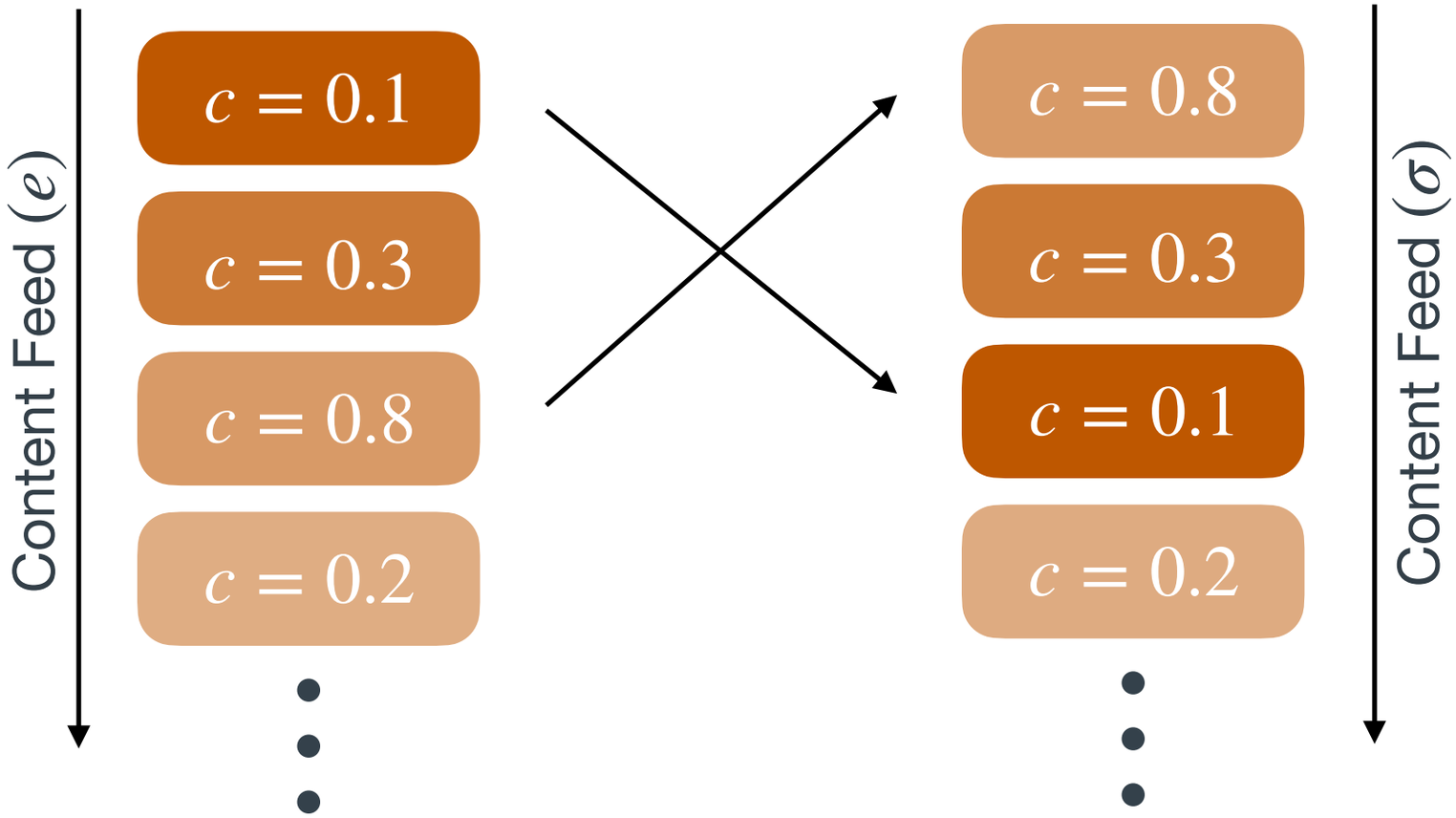

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Problem: $V(\sigma)$ is not known

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Solution: Solve a surrogate problem

$$\min_{\sigma} D(\sigma) - \sum_{p=1}^{K} q_p c_{\sigma(p)}$$

$$D(\sigma) = \sum_{i=1}^{K} |\sigma(i) - i|$$

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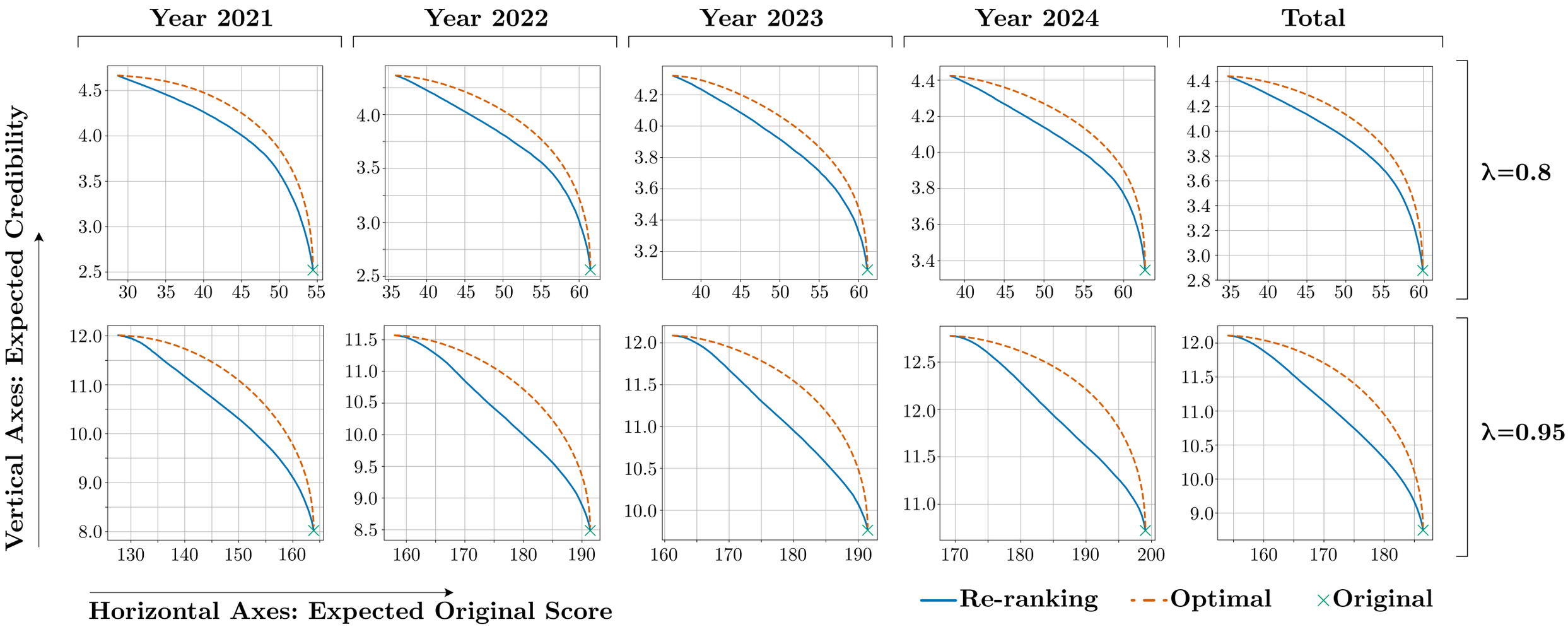
Optimality Gap



What is the cost of remaining oblivious to original cost?

Theoretically "Optimal" solutions: $\max_{\sigma \in S_K} \quad \alpha V(\sigma) + \sum_{p=1}^{K} q_p c_{\sigma(p)}$

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Concluding Remarks

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- **Challenges**:
  - Information ecosystem is not completely understood
  - Information ecosystem is fragile against adversarial attacks
  - Adversaries have initiatives
- **Future Work**:
  - How to design a robust social network?
  - Long term evolution of the network
  - How to integrate multiple information modalities?

Conclusion

Control and decision making enable new solutions for this challenge that goes well beyond fact-checking.