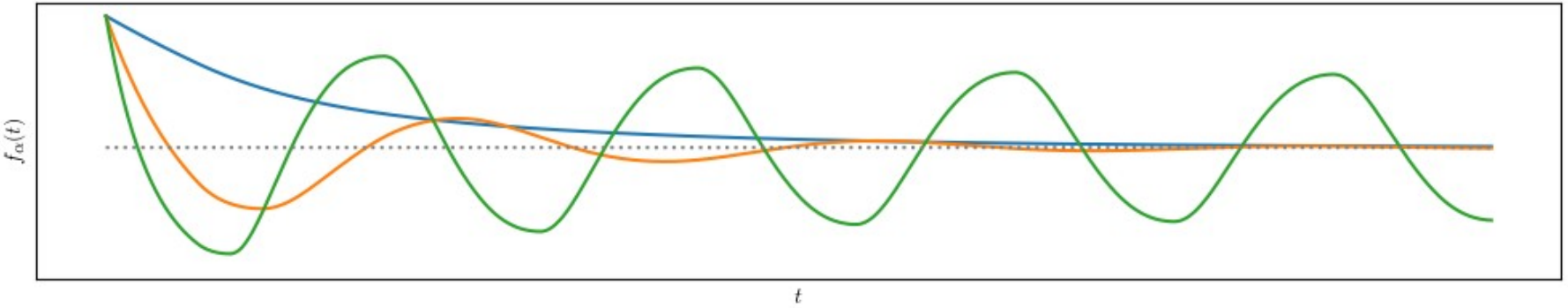

Incentivizing Stable Path Selection in Future Internet Architectures

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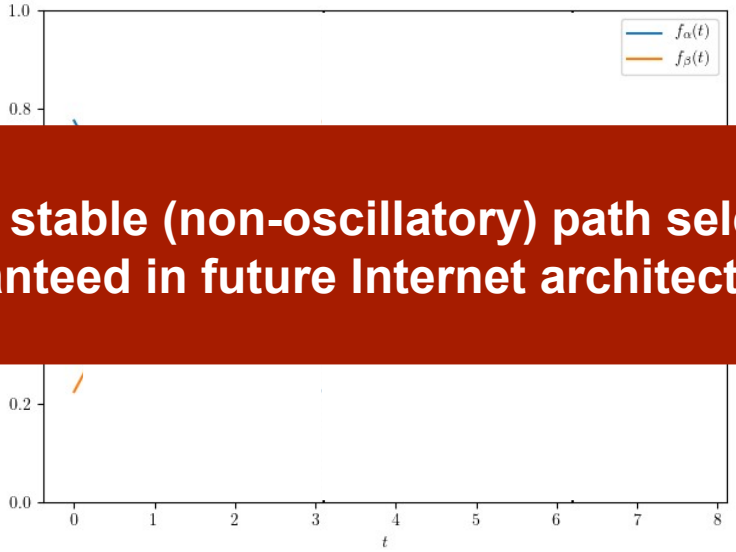
ETH zürich

Central Question of Our Paper: Stability of Path-Aware Networks (PAN)

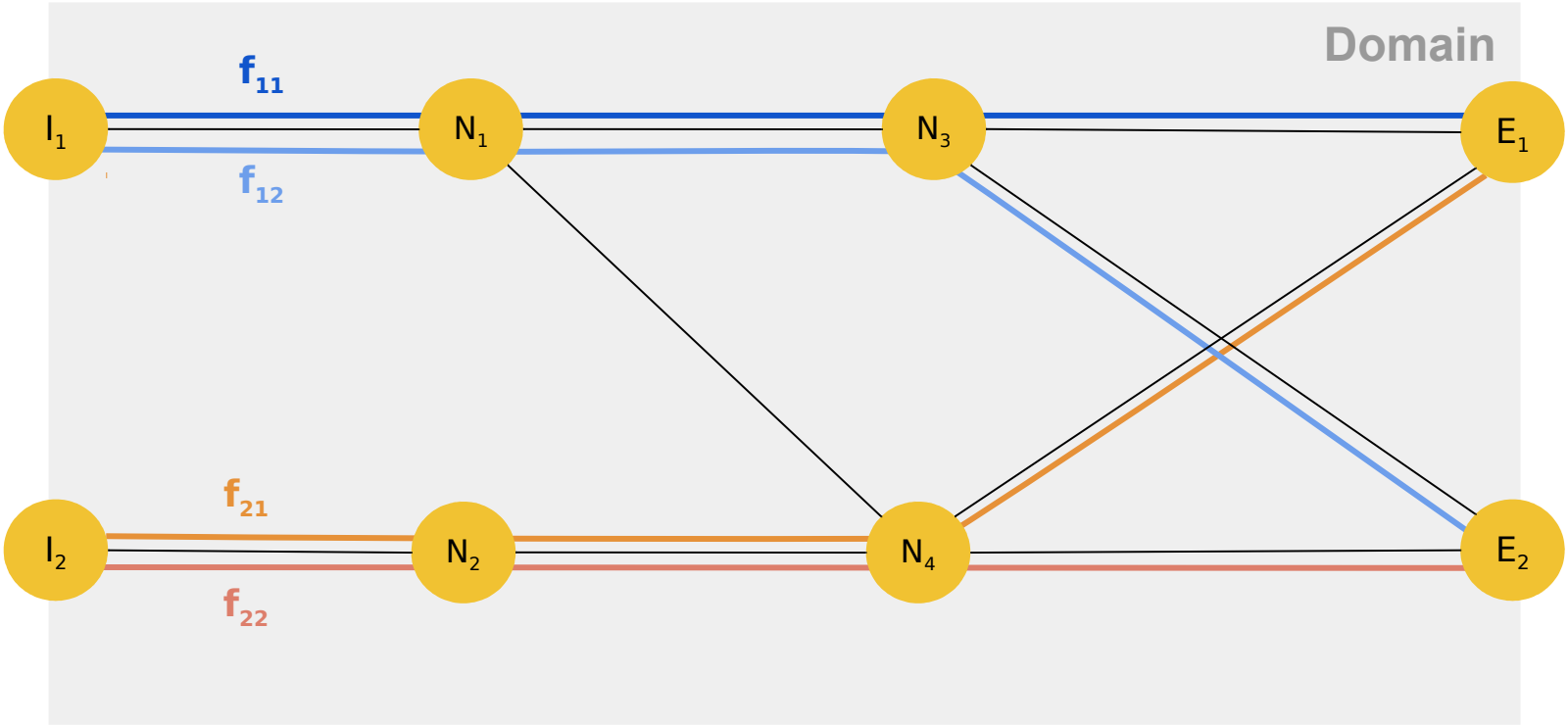
- **Vision:** Path-Aware Network (PAN) architectures allow **load-adaptive path selection** by end-hosts ⇒ increase resource utilization

- **Concern:** Load-adaptive path selection leads to **oscillation** if performed on the basis of outdated information.



How can stable (non-oscillatory) path selection be guaranteed in future Internet architectures?

Why Classic Traffic Engineering Does Not Work in a PAN Internet



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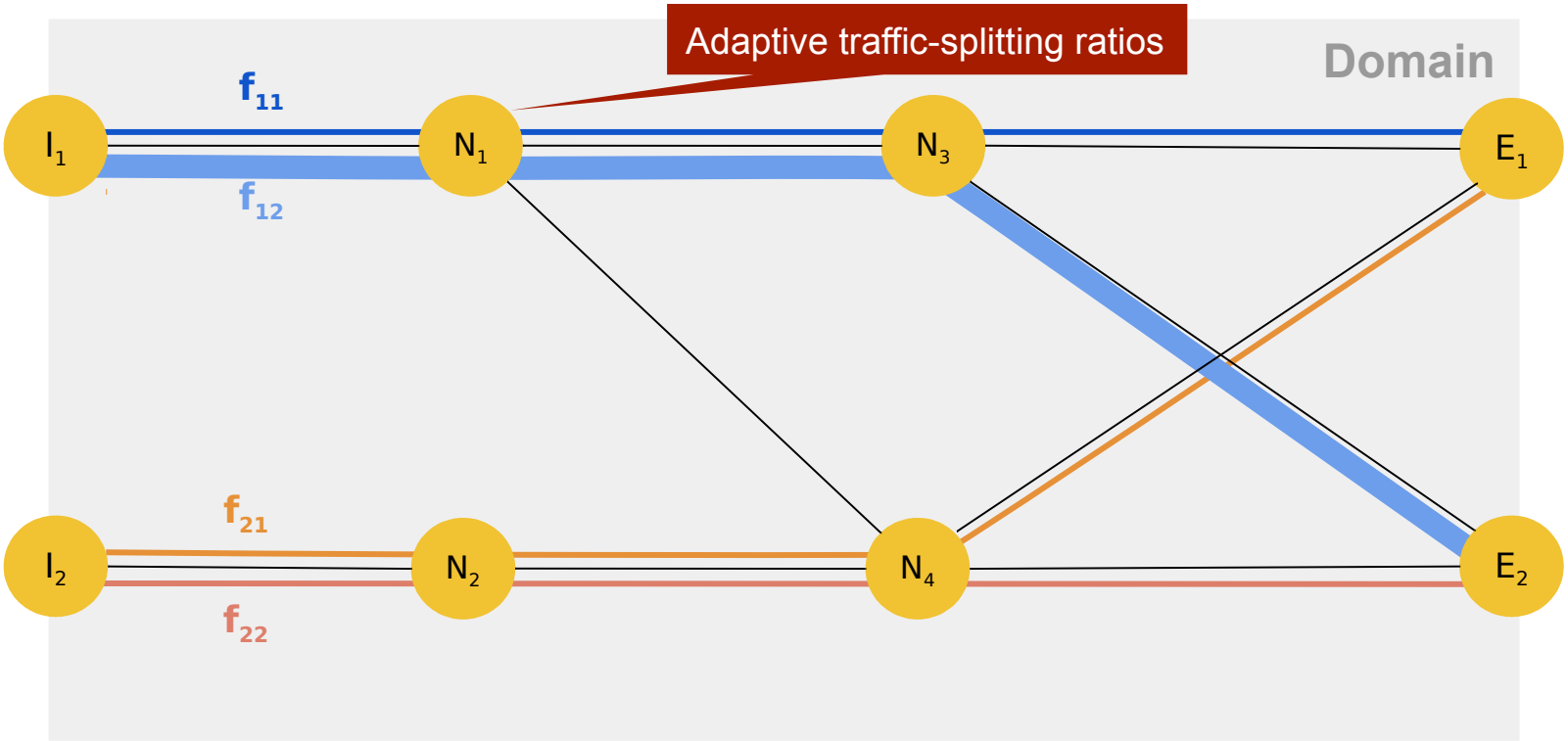

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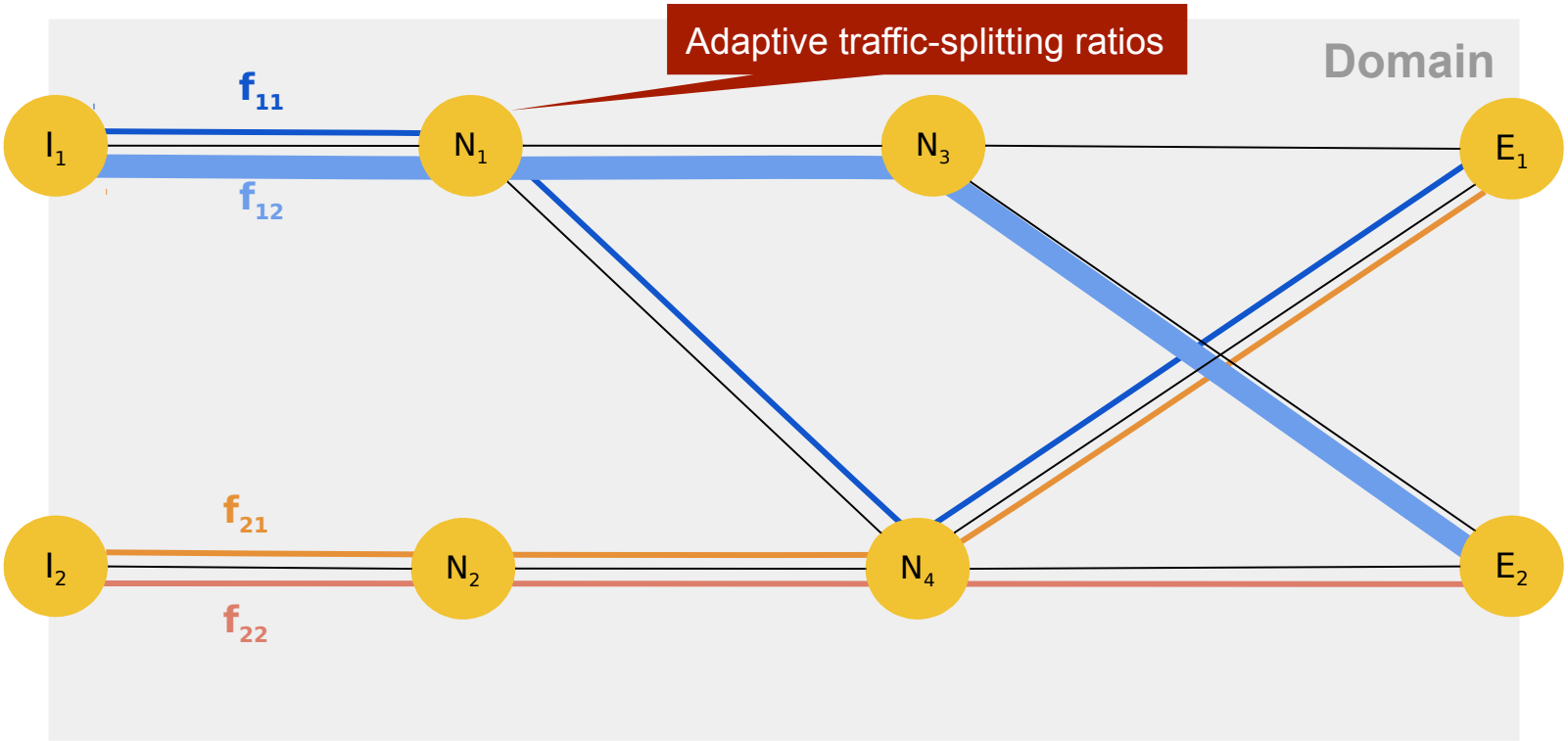

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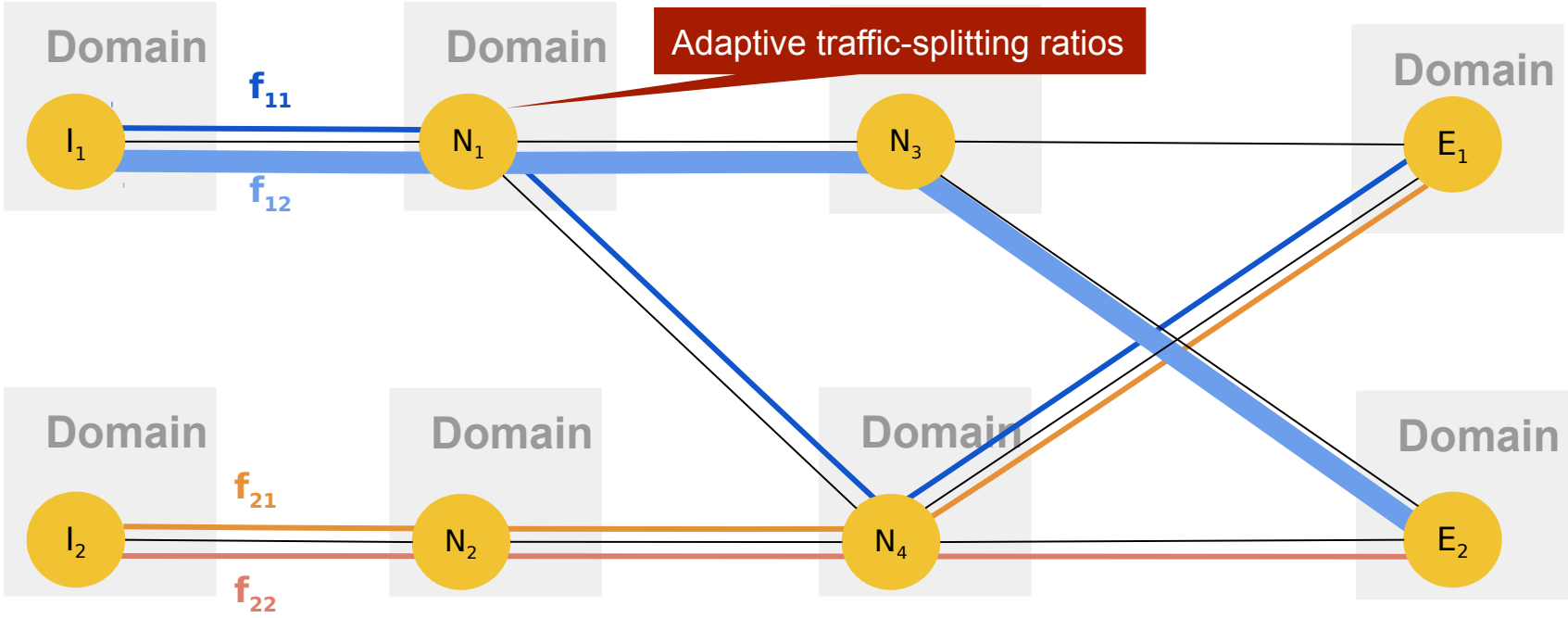
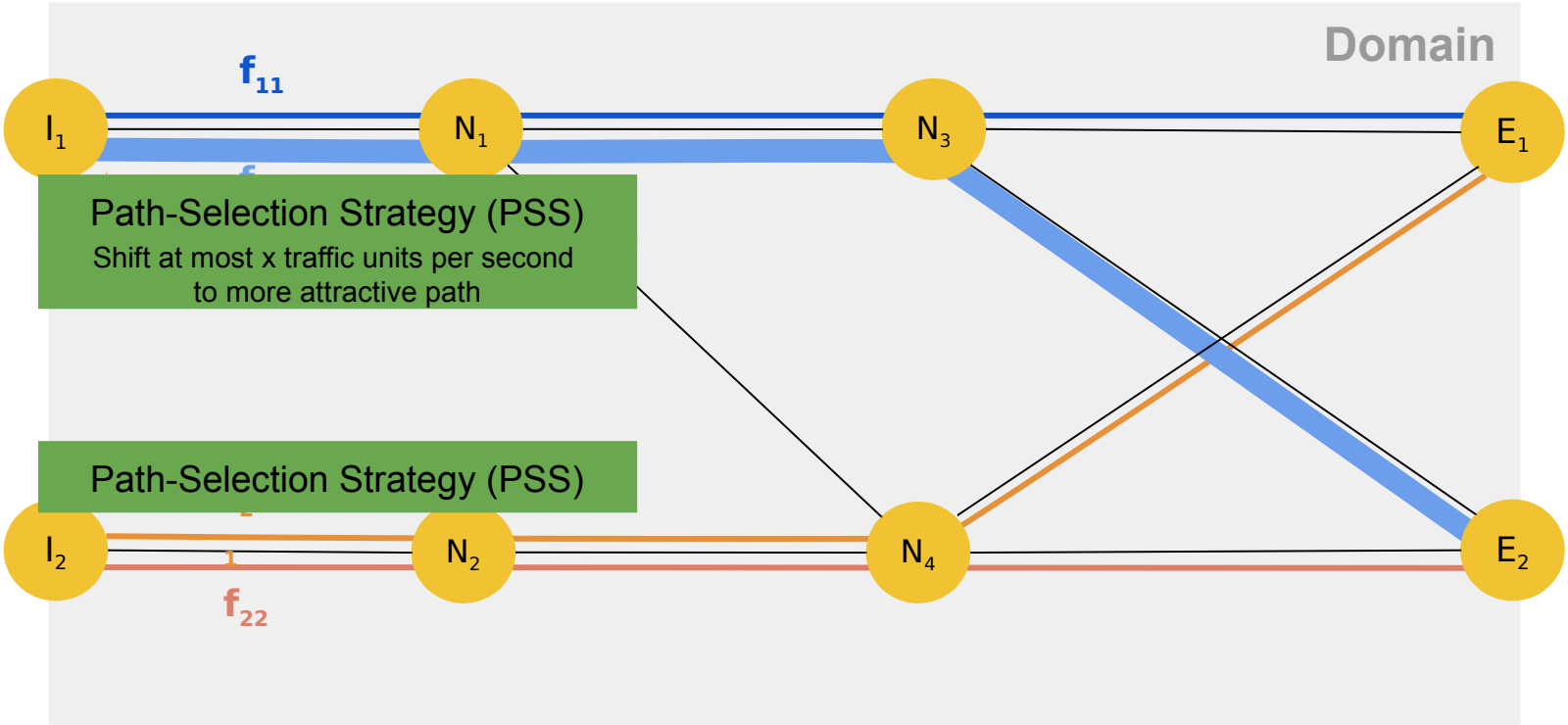


With end-host path selection, f_{11} might **have to** follow path I_1-N_1-N_3-E_1

Why Classic Traffic Engineering Does Not Work in a PAN Internet



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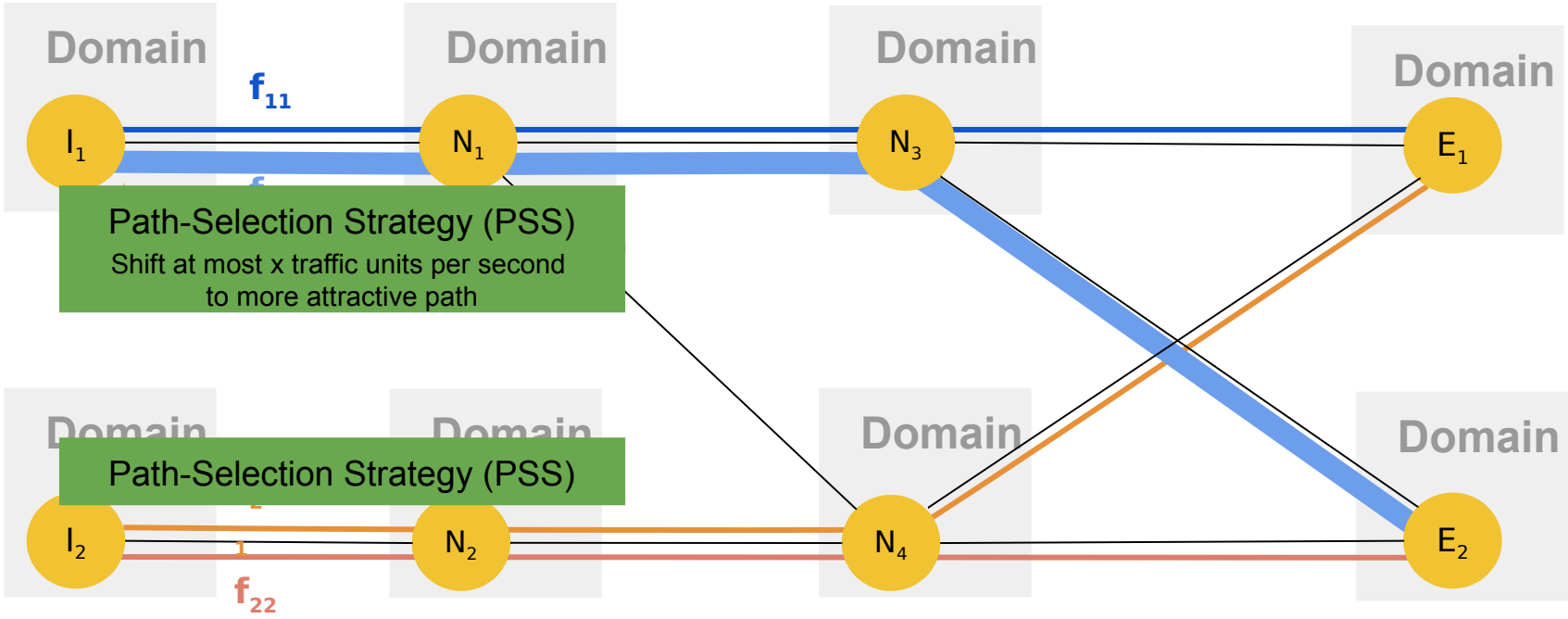


In inter-domain PAN, sources are uncontrolled and self-interested
⇒ only adopt PSS that are optimal from their individual perspective

Inter-Domain Viability of Stable Path-Selection Strategies?

- **Game-theoretic question:**

Will the path-selection strategies (PSS)
designed for stable path selection
be adopted by self-interested sources?

Do these stable path-selection strategies
form a Nash equilibrium?

Non-Oscillatory PSS

- **Non-Oscillatory PSS proposed by Fischer and Vöcking (2009):**
  - Path-switching probability is linear in load difference of paths
  - Linear coefficient has to respect a system-dependent upper bound to guarantee convergence
- Other PSS such as MATE (2002), Proportional Sticky Routing (2002), TeXCP (2005) etc. are structurally equivalent
  - Key idea: Reduce the migration rate between paths such that there is a strong congruence between perception and reality of the network state

Game-Theoretic Framework: Dynamic Routing Game

Selfish sources will only adopt PSS that form **PSS equilibria**:

- **PSS equilibrium:**
  - A strategy is a PSS equilibrium strategy

    iff given that every end-host in the network adopts the strategy,

    there is no other strategy that allows an individual end-host to reduce its cost

Do Non-Oscillatory PSS Constitute PSS Equilibria?

No!

- Universal adoption of non-oscillatory PSS
  makes adoption of oscillatory PSS worthwhile

- Stable path selection cannot be achieved by relying purely on end-hosts
  ⇒ Incentivize stable path selection with *mechanisms*

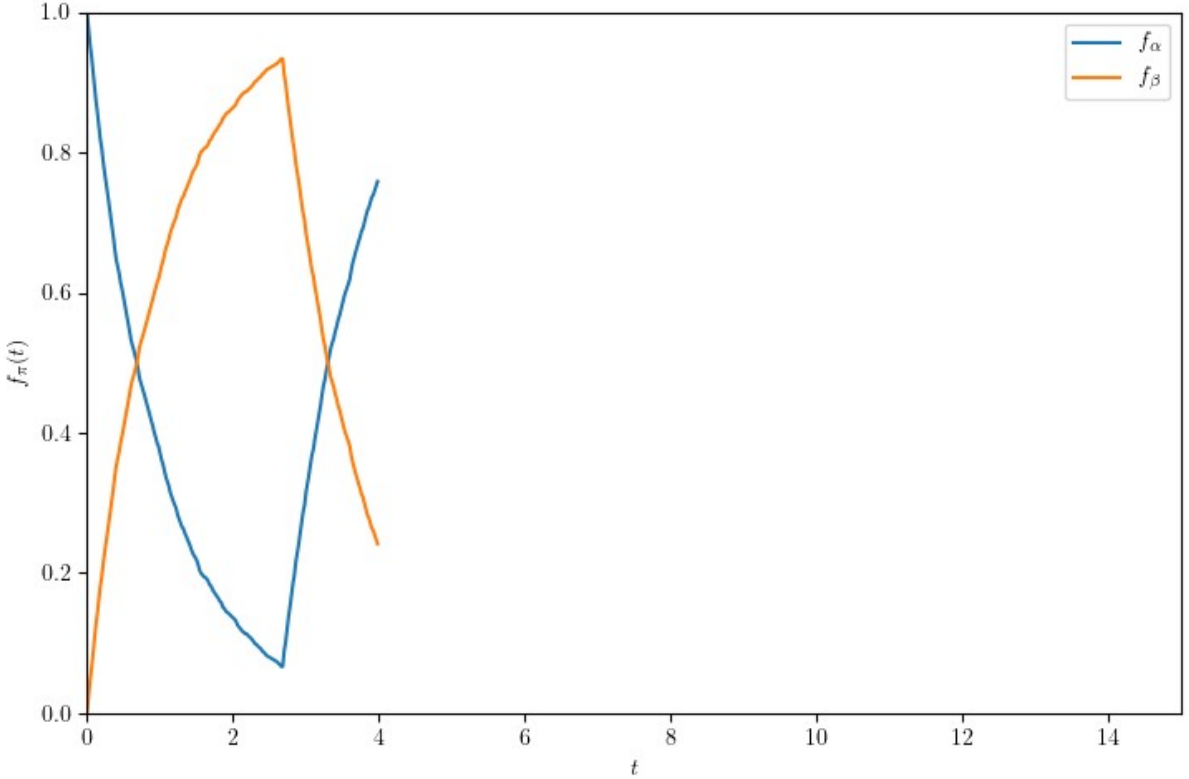
Incentive-Compatible Stabilization Mechanisms

- **Idea:**
  - Mechanism should alter the cost of PSS
    (with monitoring, punishments, requirements, etc.)
    such that a non-oscillatory PSS becomes a PSS equilibrium strategy
- We design two stabilization mechanisms and
  formally prove their incentive compatibility:
  - FLOSS mechanism (presented here)
  - CROSS mechanism (see in paper)

Flow-Loyalty Oscillation Suppression System (FLOSS)

- **Idea:**
  - Using path during a certain time interval requires a *registration*
    (no registration ⇒ packets are dropped)
  - Registrations are selectively granted:
    - Loyal end-hosts (end-hosts using the path in the current interval) always get a registration for the next interval
    - The amount of registrations available to end-hosts from other paths is limited ⇒ restrict arbitrary path migration
  - Enforce migration volume per interval to iteratively achieve equal load

Flow-Loyalty Oscillation Suppression System (FLOSS)



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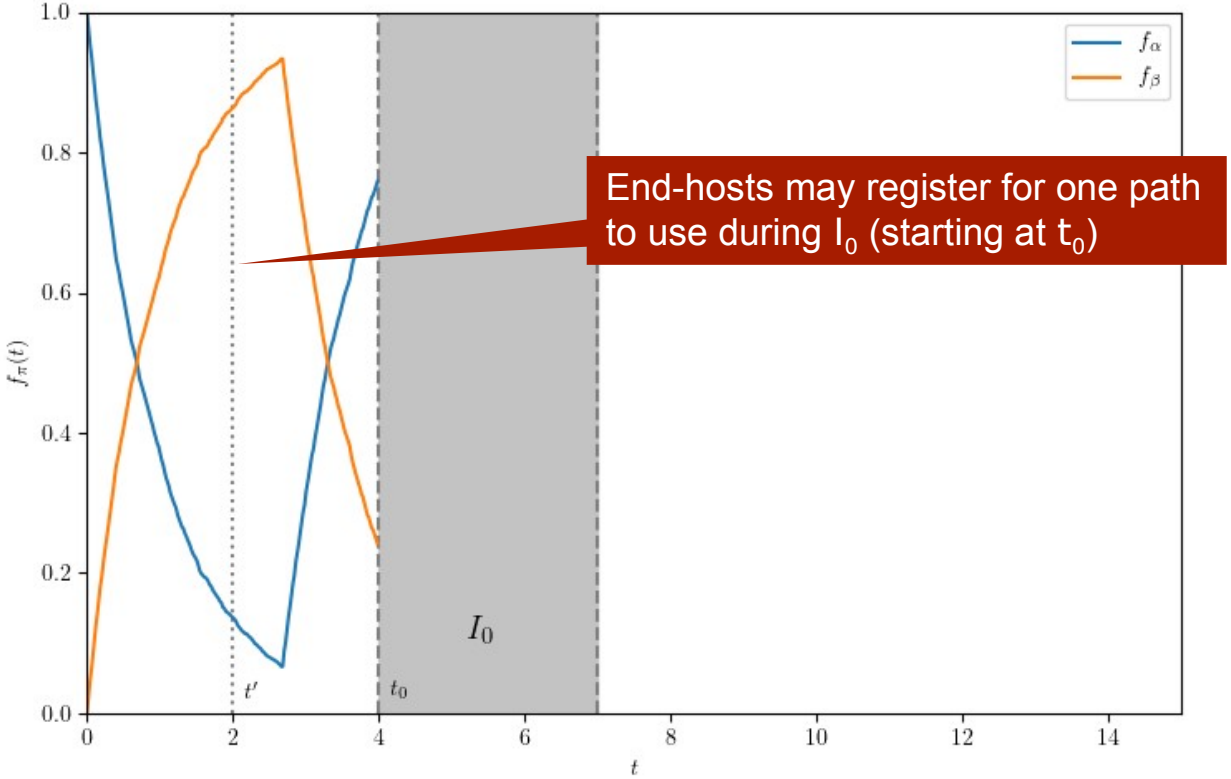
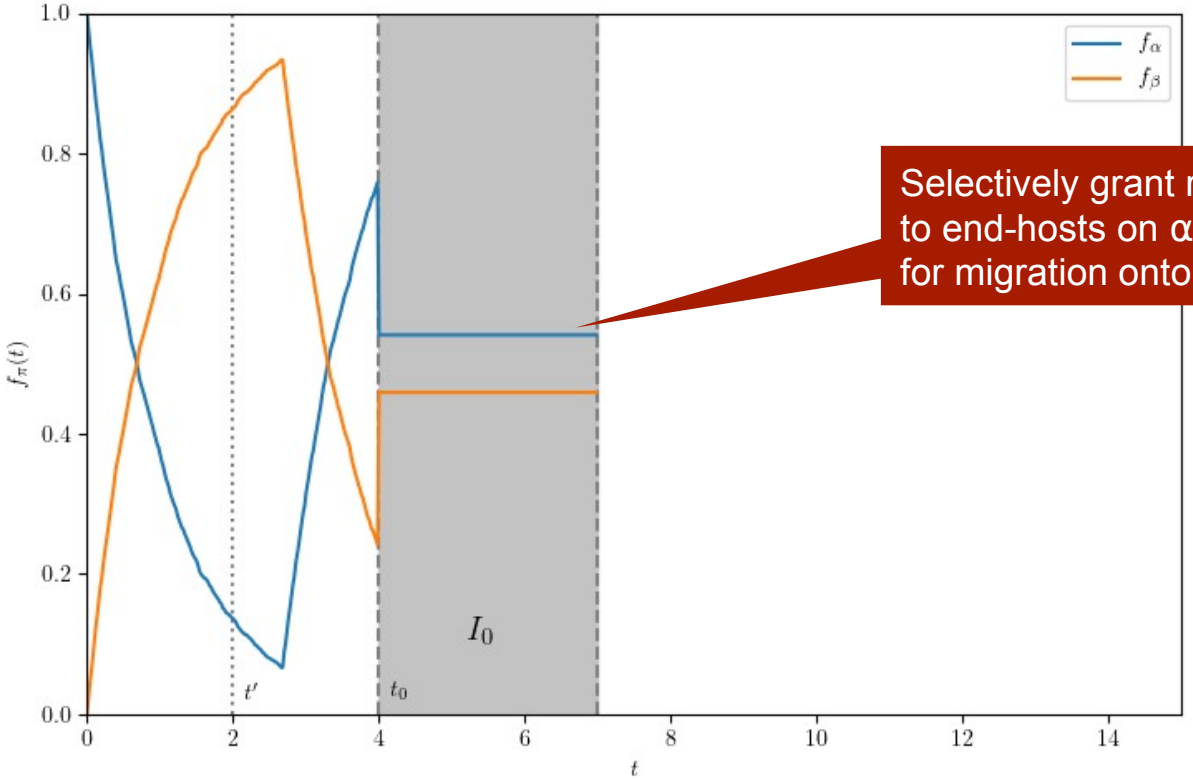


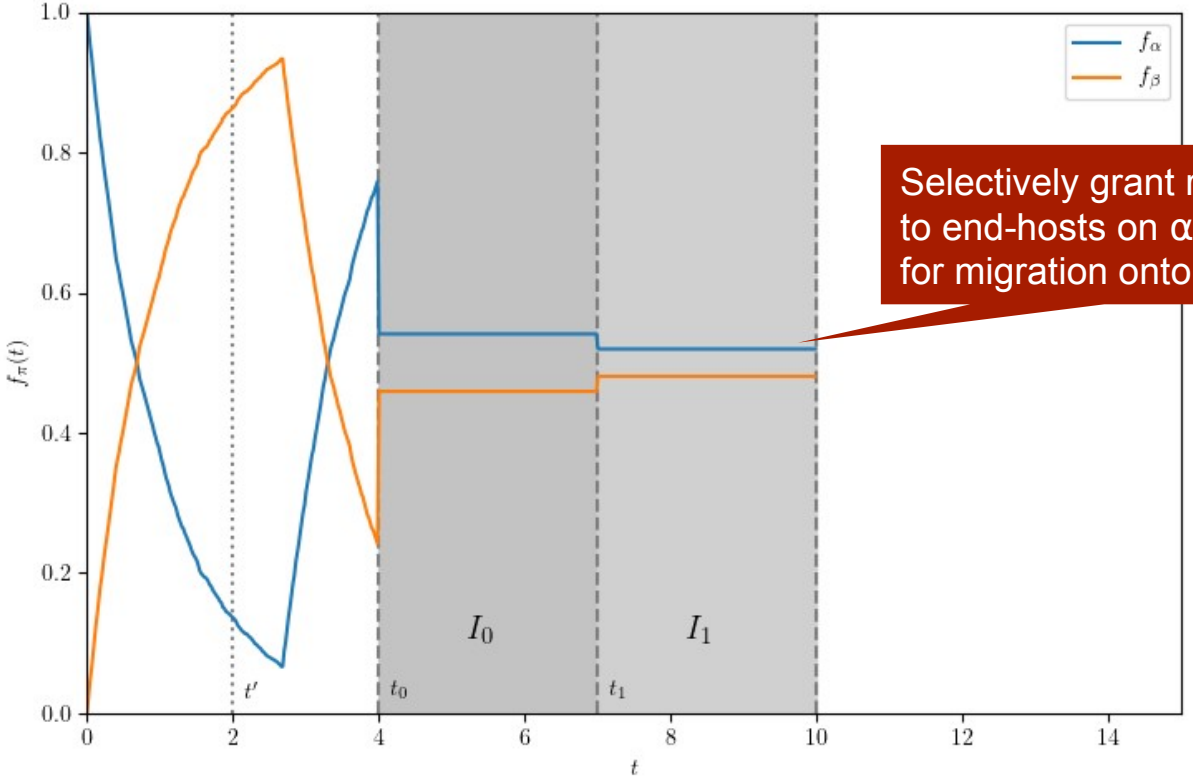
End-hosts may register for one path to use during I_0 (starting at t_0)

Flow-Loyalty Oscillation Suppression System (FLOSS)



Selectively grant registrations
to end-hosts on α
for migration onto β

Flow-Loyalty Oscillation Suppression System (FLOSS)



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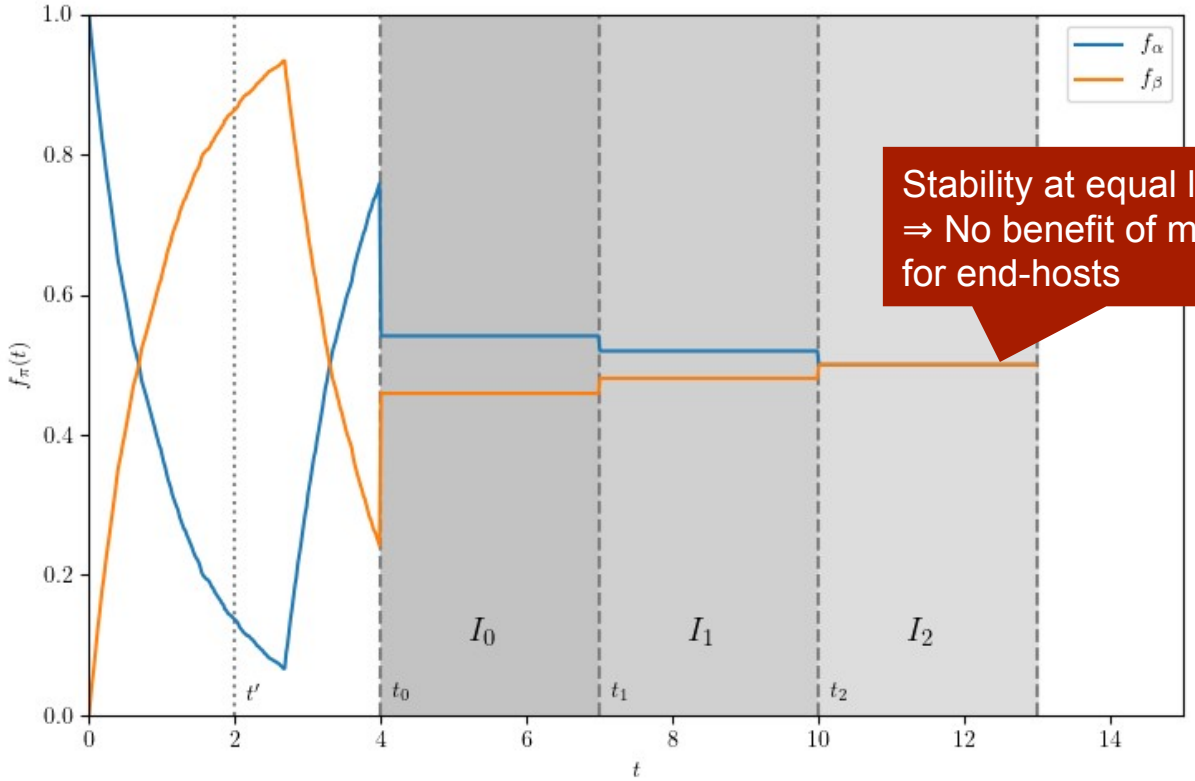
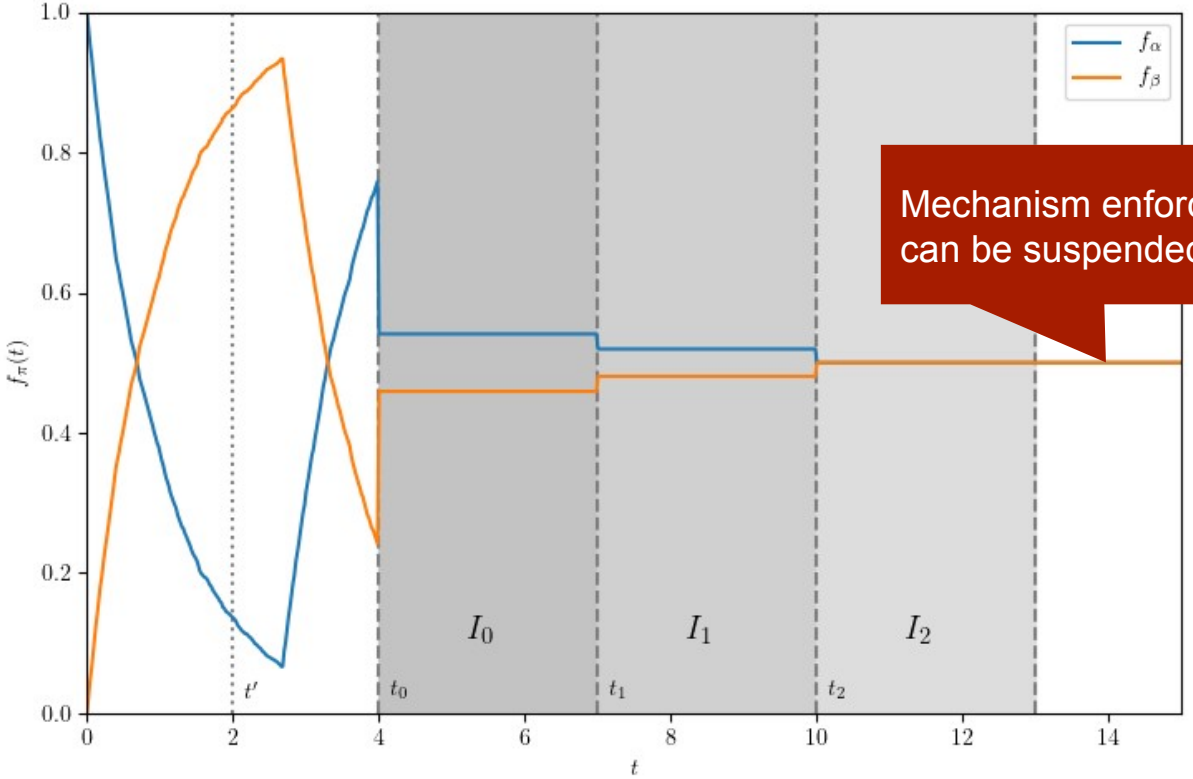


Stability at equal load
⇒ No benefit of migration for end-hosts

Flow-Loyalty Oscillation Suppression System (FLOSS)



Mechanism enforcement can be suspended

Summary

Scheme	Stability	End-Host Path Selection	Incentive Compatibility
AMP (2003)			
ReplEx (2006)			
Homeostasis (2009)			
HALO (2014)			
Proportional Sticky Routing (2002)			
MATE (2002)			
Kelly & Voice (2005)			
TeXCP (2005)			
Fischer & Vöcking (2009)			
OPS (2017)			
FLOSS (2020)			
CROSS (2020)			

Our paper presents a game-theoretic framework that allows to analyze whether

- a path-selection strategy is adopted by rational end-hosts (Does it form a PSS equilibrium?)
- a stabilization mechanism is incentive-compatible

Game-theoretic perspective is important to consider in path-aware Internet architectures!