# FMitF: Track I:
# Principles for Modular Probabilistic Programming and Inference

PI Holtzen

Co-PI Ahmed

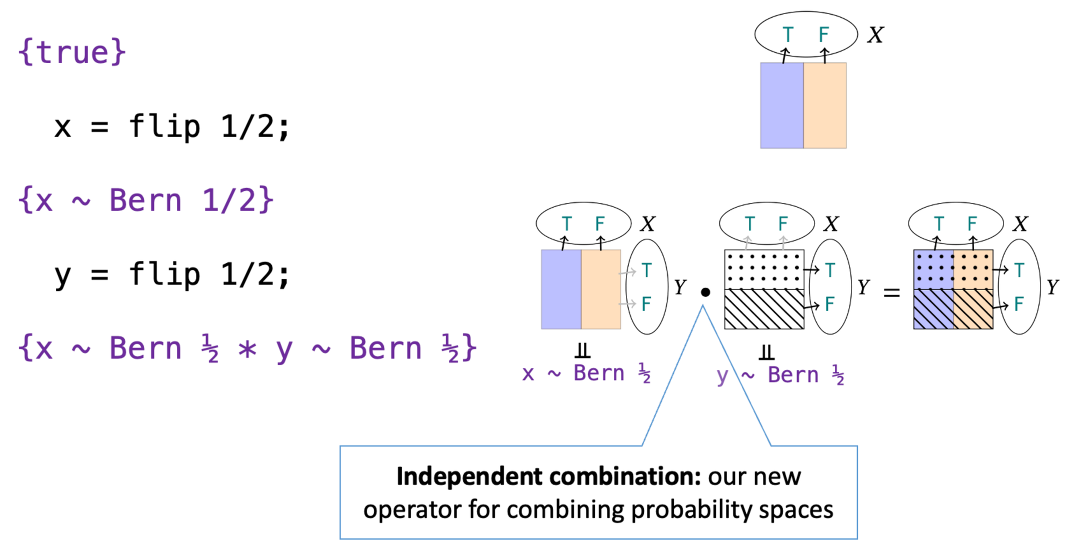

**PI Steven Holtzen**, Assistant Professor, Northeastern University. [s.holtzen@northeastern.edu](mailto:s.holtzen@northeastern.edu)

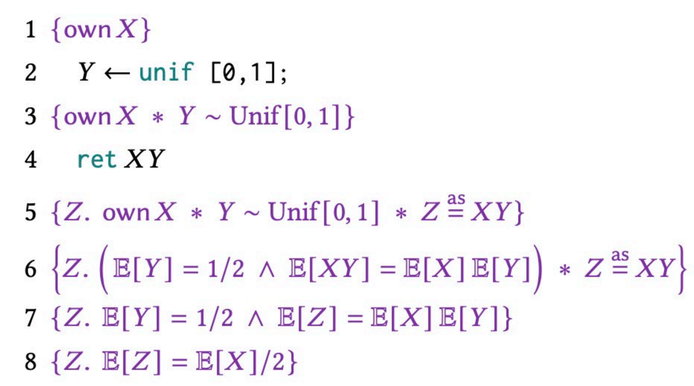
**Co-PI Amal Ahmed**, Professor, Northeastern University. [amal@ccs.neu.edu](mailto:amal@ccs.neu.edu)



https://www.nsf.gov/awardsearch/showAward?AWD_ID=2220408


Project page: https://neuppl.khoury.northeastern.edu/projects/fmitf/



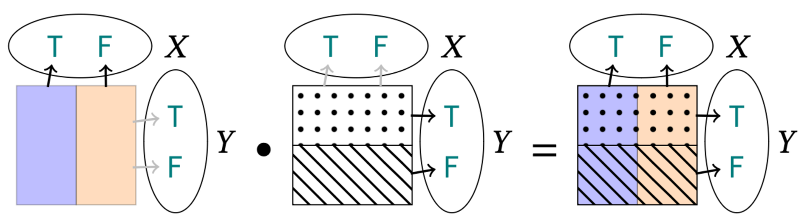

## Overview and Motivation of Key Problems

- *Context*: Probability is everywhere in today's systems: it comes from machine learning, randomized algorithms, computer networks, distributed systems, etc.
- *Challenge*: It is extremely difficult to reason about large-scale probabilistic systems due to the inherent state-space explosion of probabilistic behavior.
- *Consequences*: (1) Today's probabilistic systems are largely unverified, (2) it is difficult to automatically determine a probabilistic system's behavior, and (3) it is difficult to design scalable probabilistic programming languages (PPLs) that are usable by practitioners.

## Approach

We design new tools and foundations for formally reasoning about the behavior of probabilistic programs by modularly decomposing large probabilistic programs into smaller ones.

1. **Lilac**: Generalize well-known techniques for managing shared mutable state (separation logics) to probability



2. **MultiPPL**: Explore new foundations for decomposing probabilistic reasoning across language boundaries with multi-language probabilistic programming.

## Scientific Impact

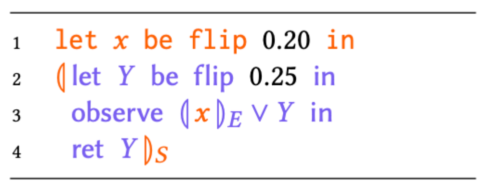
- New approaches and foundations to probabilistic separation logic that enable scalable modular verification of probabilistic systems.
- Published papers:
  - [PLDI'23] Lilac: a Modal Separation Logic for Conditional Probability. John Li, Amal Ahmed, and Steven Holtzen. In ACM SIGPLAN Conference on Programming Language Design and Implementation (PLDI), 2023.
  - [LICS'24] A Nominal Approach to Probabilistic Separation Logic. John M. Li, Jon Aytac, Philip Johnson-Freyd, Amal Ahmed, and Steven Holtzen. In ACM/IEEE Symposium on Logic in Computer Science (LICS), 2024.
- Connecting to broader formal methods research:
  - Combining *probabilistic inference* and *separation logic*
- New course material taught at the Oregon Programming Languages Summer School

## Solutions

**Lilac: A new separation logic for probability [PLDI'23, LICS'24].**

- *Key contributions*: (1) A new measure-theoretic form of probabilistic separation logic; (2) a modal treatment of conditioning; (3) a new category-theoretic foundation for probabilistic separation logics.
- *Applications*: Verified sampling sampling algorithms
- *Future work:* Further unification of probability and non-determinism; integrating observation into Lilac; mechanization in a proof assistant

**Multi-language probabilistic programming**




- *Key contributions*: A new approach to probabilistic programming that enables program interoperation, allowing programmers to flexibly mix and match inference algorithms and language features.
- *Applications*: Scalable probabilistic programs that combine exact and approximate inference.
- *Future work:* Incorporating more advanced inference strategies

## Broader Impact on Society

- More scalable probabilistic programming languages for democratizing machine learning. Tools being adopted by Sandia National Laboratories.
- Statistical literacy: using programs to help people reason about probabilistic uncertainty.
- Improved reliability of randomized algorithms and machine learning through foundational verification.

## Broader Impact on Education

- Course development: new course on probabilistic programming https://neuppl.github.io/CS7470-Fall23/
- Lecture series at OPLSS 2024 https://www.cs.uoregon.edu/research/summerschool/summer24/topics.php#Holtzen
- 1 undergraduate trained (Jack Czenszak)
- 2 PhD. students trained (John M. Li, Sam Stites)
- Future goals: incorporating probabilistic programming languages into courses

## Broader Impact on Participation

- Broad outreach at Oregon Programming Languages Summer School (OPLSS) 2024. Over 150 student attendees.
- Presenting at Programming Languages Mentorship Workshop at PLDI 2023. Over 40 student attendees.

Link to project page: