Chapter 1

Introduction and Motivation

1.1 Why Focus on the NFL

"Why NFL?" — arguments: liquidity, data richness, bookmaker sophistication

Modern quantitative sports analytics has progressed rapidly in domains like baseball and soccer, yet the **National Football League (NFL)** remains underexploited in many respects. There are three key reasons to center a dissertation on the NFL:

- **High liquidity, deep betting market.** The NFL betting ecosystem is vast, with many sportsbooks, sophisticated bettors (sharps), and numerous betting markets (spread, total, moneyline, prop bets). This creates a rich environment for modeling "market efficiency" and testing edges.
- **Abundant, granular data.** The NFL provides detailed play-by-play data, player tracking, and advanced metrics (e.g. EPA, success rate, win probability). This richness enables more refined models than simpler aggregate sports.
- **Complex strategic decisions.** Football has sequential decision-making (downs, timeouts, fourth-downs), making it a natural candidate for reinforcement learning and dynamic modeling. It's not just "team strength" but in-game tactics.

Because the NFL lies at the intersection of statistical modeling, machine learning, and decision analytics, a dissertation in this domain can yield both deep theoretical contributions and valuable practical tools.

1.2 Research Questions and Objectives

This dissertation seeks to address the following core questions:

1. **How to build a hybrid predictive architecture** that integrates classical models, modern machine learning, and reinforcement learning for NFL betting?

2. **Can we quantify and leverage model uncertainty** to inform betting strategy (e.g. fractional Kelly, risk-aware allocations)?
3. **What is the marginal value of various feature classes** (injuries, rest, weather, market signals) in predictive performance and betting edge?
4. **Can simulation and strategy evaluation reveal exploitable inefficiencies** (middling, teasers, correlated parlays) under realistic distributions?
5. **How to operationalize all of the above** in a polished system-of-systems (governance, modular design, experiment tracking) that can be used on a laptop and on GPU servers?

Achieving these contributes:

- A **unified modeling framework** for NFL prediction that blends classical and RL approaches.
- A **risk-aware betting module** grounded in posterior uncertainty.
- A **simulation engine** for strategy evaluation under realistic outcome distributions.
- A **productionizable system architecture** with experiment governance and modular extensibility.

1.3 Contributions and Claims

The main contributions of this work will be:

- A comparative evaluation of classical (GLM, Poisson, state-space) and RL-based models in the NFL domain, validated by betting return and calibration.
- A method for propagating posterior uncertainty into betting decisions, including use of fractional Kelly and drawdown constraints.
- A simulation suite that translates predicted distributions into strategy-level evaluation (teasers, middling, hedges).
- A modular, reproducible software architecture (Docker / uv / dual-mode GPU + native) with experiment tracking and model versioning.
- Empirical insights on feature importance (injuries, rest, travel, market microstructure) and narrative storytelling of "why the model bets what it does."

1.4 Dissertation Structure

Below is a brief road map of this dissertation:

- **Chapter 2: Literature Review** — survey of classical and modern models in sports prediction, betting markets, RL in game domains.
- **Chapter 3: Data Foundations and Feature Engineering** — discussion of NFL data sources, structure, preprocessing, feature catalogs, era handling.
- **Chapter 4: Baseline Models** — implementation and calibration of GLM, state-space, Poisson, and classical benchmarks.
- **Chapter 5: Reinforcement Learning Framework** — state/action/reward specification, offline RL design, training pipelines.
- **Chapter 6: Uncertainty & Risk Management** — posterior distributions, risk-aware betting, Kelly strategies, drawdown analysis.
- **Chapter 7: Simulation & Strategy Testing** — Monte Carlo engines, teasing, parlays, correlated outcomes, strategy performance.
- **Chapter 8: System Architecture & Governance** — modular pipeline, experiment tracking, deployment strategy, version control.
- **Chapter 9: Results, Ablations, Discussion** — comparative performance, feature ablations, robustness, error analysis.
- **Chapter 10: Conclusion and Future Work** — summary of findings, limitations, and opportunities ahead.
- **Appendices** — extended figures, proofs, code reference, glossaries.

1.5 Technical Approach Overview

At a high level, the system will operate in layers:

- A data ingestion and feature pipeline — building situational, team-level, market-level features.
- Classical and benchmark models (GLM, Poisson, state-space) to form priors and baselines.
- An RL agent (e.g. DQN, PPO) that takes feature + market state to decide bets or allocations.
- Uncertainty propagation (posterior distributions, bootstrap ensembles) to inform risk control.

- A simulation engine that translates distributions into actionable betting strategies.
- An evaluation and governance layer to compare models, version them, log experiments, and deploy.

We'll later formalize the RL state/action space and reward in Chapter 5.

1.6 Glossary of Key Terms

Here are some terms you'll see frequently:

CLV: Closing Line Value — difference between market-implied and model-implied edge.

Kelly Fraction: Optimal fraction of bankroll to stake given edge and odds.

Posterior Uncertainty: Bayesian credible intervals on model predictions.

Middling / Teasers: Betting strategies that exploit distributions across markets.

Feature ‹class›: A group of inputs, e.g. injuries, rest, market signals.

Ensemble: A weighted combination of predictions from multiple models.

1.7 Writing and Style Notes

I will adopt a fluid narrative style augmented with margin notes, side visualizations, and sparklines (Tufte-inspired). Figures will often be annotated inline and cross-referenced precisely. Each chapter will begin with a roadmap and end with a takeaway summary.

Refine this introduction after drafting all chapters — sometimes purpose evolves.