# Olympic Medal Prediction via Adaptive Triple-Fusion: Combining AAC Model with ARIMA-State Space Dynamics

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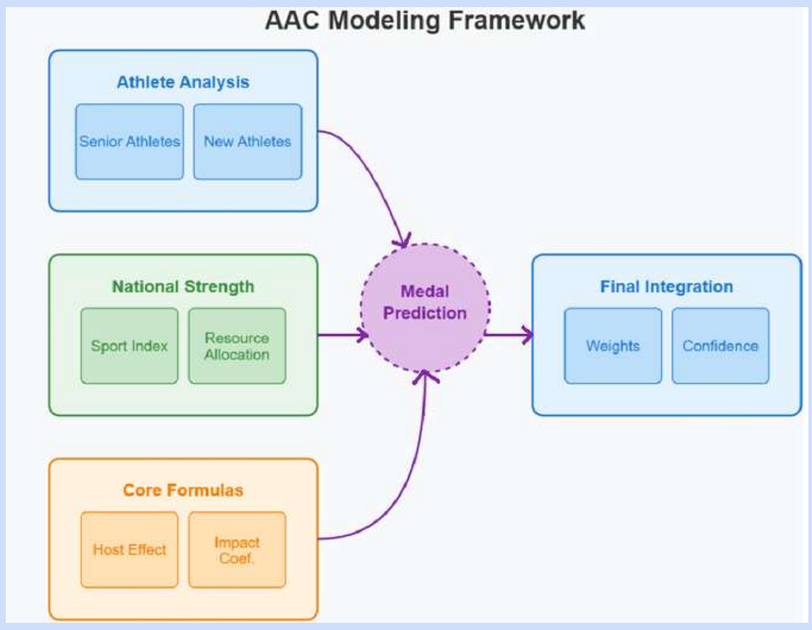
## Introduction

☼ The Olympic Games have turned into a highly complex dynamic network, the prediction of medals demands an analysis of multiple interactive subsystems like athlete development, national training systems, and the global regime of competitions.

**Developments of Olympic prediction methods**

| | |
|---|---|
| **Initial inventing stage (1990-2005)** | Mathematical method without time differences |
| **Second stage (2006-2015)** | Time series analysis for national strength modeling |
| **Current stage (2016-current)** | Development of high-accuracy ML models (at the cost of interpretability) |

## AAC (senior Athlete-new Athlete-Country) Model




For athlete $i \in \mathcal{A}$ , the state vector evolves as:

$$\mathbf{X}_{i,t} = \begin{bmatrix} P_{part}(t) \\ P_{perf}(t) \\ A_{eff}(t) \\ S_{str}(t) \end{bmatrix}$$

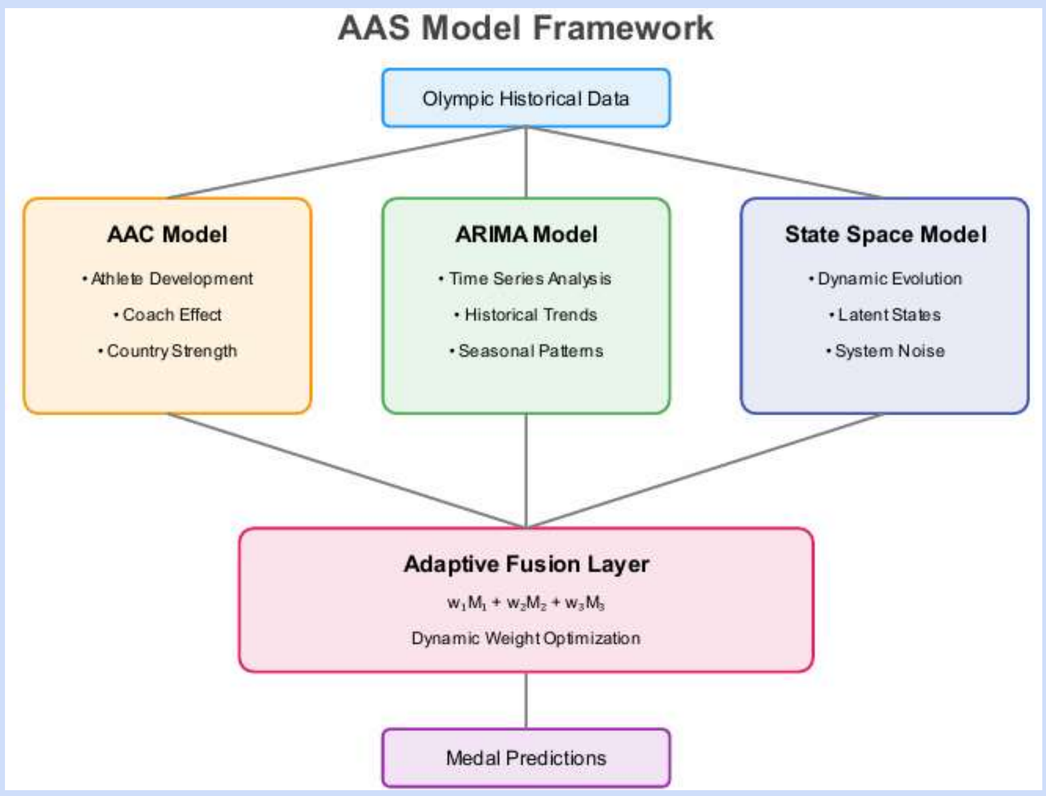
Following the stochastic differential equation:

$$d\mathbf{X}_{i,t} = \mu(\mathbf{X}_{i,t}, \theta)dt + \sigma(\mathbf{X}_{i,t}, \theta)dW_t$$

The model incorporates two key temporal effects:

- **Historical influence decays exponentially over time**, reflecting the diminishing relevance of past performances;
- **Performance correlation between different time points decreases with temporal distance**, capturing the natural evolution of athletic capabilities.

## AAS (Adaptive ARIMA-AAC-State Space) Fusion Model




The AAS model introduces a triple-fusion framework integrating:

**A**. Micro-level athlete dynamics (AAC)
**A**. Macro-level time series patterns (ARIMA)
**S**. Dynamic state evolution (State Space)

The AAS fusion estimator achieves minimal variance:

$$\widehat{M}_{AAS} = \min_{\widehat{M}} \left\{ \mathbb{E}\left[ \left( M - \widehat{M} \right)^2 \right] \right\}$$

subject to: $\widehat{M} = w_{AAC}M_{AAC} + w_{ARIMA}M_{ARIMA} + w_{SS}M_{SS}$, $\sum w_i = 1, \quad w_i \geq 0$

## Coach Effect Integration

The coach effect model captures 3 key aspects:

- **Technical expertise transfer**
- **Institutional memory effects**
- **Sport-specific adaptation**

This provides a quantitative framework for evaluating coaching impact on Olympic performance.

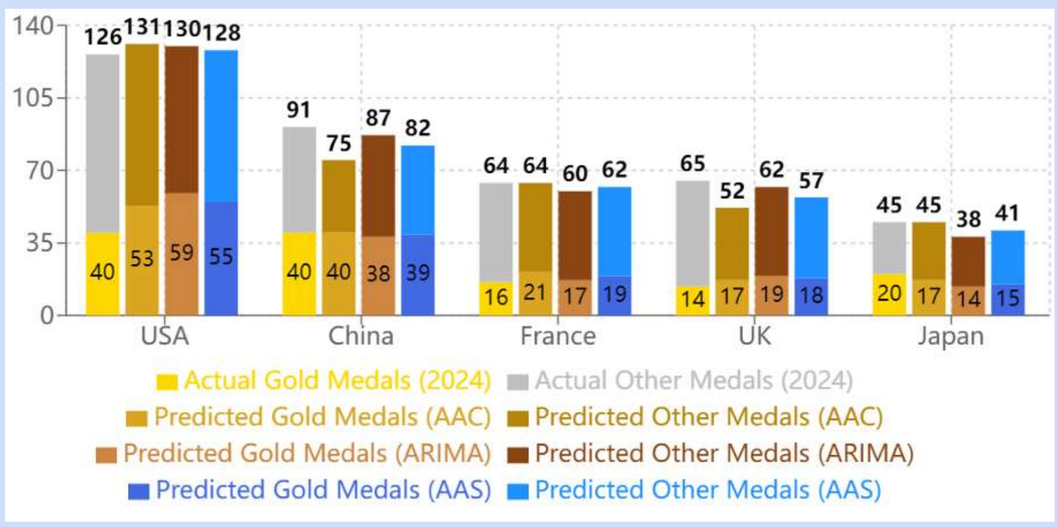
## Model Validation and Performance Assessment

Our empirical validation leverages data from the 2024 Olympics to rigorously evaluate the predictive capabilities of the proposed AAS fusion framework against its constituent models (AAC and ARIMA). The analysis demonstrates the superior performance of our integrated approach across multiple metrics.

| Country | 2024 Olympic Medals Prediction | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Total Medals | | | | Gold Medals | | | |
| | Actual | AAC | ARIMA | AAS | Actual | AAC | ARIMA | AAS |
| USA | 126 | 115 (-8.7%) | 118 (-6.3%) | 120 (-4.8%) | 40 | 42 (+5.0%) | 41 (+2.5%) | 41 (+2.5%) |
| China | 91 | 90 (-1.1%) | 87 (-4.4%) | 89 (-2.2%) | 40 | 40 (0.0%) | 39 (-2.5%) | 40 (0.0%) |
| France | 64 | 59 (-7.8%) | 62 (-3.1%) | 61 (-4.7%) | 16 | 20 (+25.0%) | 17 (+6.3%) | 17 (+6.3%) |
| UK | 65 | 60 (-7.7%) | 63 (-3.1%) | 62 (-4.6%) | 18 | 17 (-5.6%) | 16 (-11.1%) | 17 (-5.6%) |
| Japan | 45 | 40 (-11.1%) | 42 (-6.7%) | 43 (-4.4%) | 20 | 19 (-5.0%) | 18 (-10.0%) | 19 (-5.0%) |

Note: Values in parentheses indicate relative prediction errors (- underprediction, + overprediction)

## Forward-Looking Projections: 2028 Olympics




**Key Findings:**

- USA: **128 total medals** including **55 gold medals**
- China: **82 total medals** including **39 gold medals**
- Enhanced precision with **±5.8% uncertainty intervals**
- **Mean bias** reduced to **-1.2%**

Our model projects significant dynamics for the 2028 Los Angeles Olympics, with particular attention to host nation effects and evolving competitive landscapes.

## Conclusions

This research develops and validates the AAS fusion framework to advance Olympic medal prediction. It integrates athlete dynamics and national trends, achieving <5% mean error rates for major nations in the 2024 Olympics. The framework combines measure-theoretic probability and hierarchical Bayesian modeling, ensuring robust predictions and interpretability. Empirical results show superior performance in predicting total and gold medals for top nations. Future work will explore incorporating technological impacts and demographic changes, and enhancing adaptability to rapid shifts in Olympic competition dynamics.

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