

# Predicting the Next Basketball Action with Graph Attention Networks and Large Language Models

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## Abstract

This paper evaluates whether a Graph Attention Network (GAT) can predict the next basketball action from NBA play-by-play data given the current game context and recent possession events. Each event is represented as a fully connected interaction graph over the ten on-court players, where node feature vectors combine learned player identity embeddings with engineered contextual and temporal features (e.g., score margin, clock, possession progress, and short event history). The resulting graph representation is used to predict the next game-level event label from a fixed action set. As an unstructured baseline, we evaluate a Large Language Model (LLM) (Mistral 7B) using zero-shot and few-shot prompting over textual play-by-play descriptions. Models are evaluated using Top-1 accuracy, Top-3 accuracy, macro-F1, and per-class confusion matrices. Results suggest that the LLM baseline captures coarse game flow but struggles with fine-grained event prediction, while the GAT learns useful relational structure and achieves stronger overall performance.

## 1 Introduction

Basketball is a highly interactive, multi-agent system in which the outcome of each possession is determined from coordinated decisions among players, coaches, and officials. Traditional basketball analytics often reduce this complexity to box-score summaries such as shooting percentages or aggregate counts, making it difficult to reason about how micro-context—who is on the court, recent actions, score margin, and game clock—shapes what happens next. With the increasing

availability of detailed play-by-play and tracking data, recent advances in deep learning have enabled basketball to be modeled as a structured prediction problem over interacting agents rather than as a sequence of independent events [Zhang, 2020; Wu et al., 2021].

Recent research has leveraged this structure using graph-based and attention-driven models. Prior work has shown that representing players as nodes and their interactions as edges allows graph neural networks (GNNs) to capture coordinated behavior, game tempo, and tactical intent [Zhang, 2020; Li & Jiang, 2025]. Graph attention mechanisms have been effective in modeling dynamic player relationships and temporal dependencies, outperforming sequence-only baselines on tasks such as tactical recognition, player performance forecasting, and game outcome prediction [Luo & Krishnamurthy, 2023; Zhao et al., 2025; Li & Jiang, 2025; Wu et al., 2021]. Collectively, these studies suggest that explicit relational inductive biases are well suited for basketball’s multi-agent dynamics. However, much of the existing work focuses on long-horizon targets—such as per-game statistics, tactical classes, or win-loss outcomes—collapsing many fine-grained decisions into a single label.

In this project, we instead focus on short-horizon next-event prediction, where the goal is to predict what happens immediately next in an NBA possession given the current game context and recent play-by-play history. Rather than predicting a specific player’s next action, we model the next game-level event, which includes on-court actions (shots, rebounds, fouls) as well as administrative or strategic events (timeouts, substitutions, ejections). This formulation reflects the structure of play-by-play logs, where many meaningful events are not

<sup>78</sup> attributable to a single player’s intention but still <sup>129</sup> **2.1 Task Definition**  
<sup>79</sup> determine possession flow.

<sup>80</sup> To model this problem, each event is  
<sup>81</sup> represented as an interaction graph over the ten on-  
<sup>82</sup> court players, where nodes correspond to players  
<sup>83</sup> and edges represent potential interactions between  
<sup>84</sup> all player pairs. We adopt this player-only graph  
<sup>85</sup> design because players are the central decision-  
<sup>86</sup> making agents consistently observable in play-by-  
<sup>87</sup> play data, while other potential entities (e.g., the  
<sup>88</sup> ball or spatial tracking states) are not reliably  
<sup>89</sup> available in the dataset. Node features combine  
<sup>90</sup> learned player identity embeddings with  
<sup>91</sup> engineered contextual and temporal features that  
<sup>92</sup> encode lineup configuration, possession progress,  
<sup>93</sup> and short event history. A Graph Attention Network  
<sup>94</sup> (GAT) processes these graphs to predict the next  
<sup>95</sup> event label.

<sup>96</sup> To contextualize the benefits of explicit  
<sup>97</sup> relational structure, we additionally evaluate a  
<sup>98</sup> Large Language Model (LLM) baseline that  
<sup>99</sup> performs zero-shot and few-shot next-event  
<sup>100</sup> prediction from textual play-by-play descriptions.  
<sup>101</sup> Across multiple evaluation metrics, the graph-  
<sup>102</sup> based model provides more reliable fine-grained  
<sup>103</sup> next-action predictions than the unstructured  
<sup>104</sup> language baseline, particularly for events governed  
<sup>105</sup> by possession structure and game context.

## <sup>106</sup> **2 Methods**

<sup>107</sup> We model next-action prediction in basketball  
<sup>108</sup> as a structured multi-agent learning problem. Each  
<sup>109</sup> play-by-play event is represented as a graph  
<sup>110</sup> snapshot over the ten on-court players, where node  
<sup>111</sup> features encode player identity, event participation,  
<sup>112</sup> and contextual game state (e.g., time remaining,  
<sup>113</sup> score margin, possession progress, and recent event  
<sup>114</sup> history). A Graph Attention Network (GAT) is  
<sup>115</sup> trained to predict the next event label in the  
<sup>116</sup> possession sequence. In addition, we evaluate an  
<sup>117</sup> LLM baseline that predicts the next action directly  
<sup>118</sup> from textual play-by-play descriptions, enabling  
<sup>119</sup> comparison between explicit relational modeling  
<sup>120</sup> and unstructured language-based prediction.

<sup>121</sup> Workflow Overview:

- <sup>122</sup> 1.) Segment game into possessions
- <sup>123</sup> 2.) Reconstruct 10-player lineup per event
- <sup>124</sup> 3.) Build fully-connected player graph + node  
features
- <sup>126</sup> 4.) Train GAT to predict next event label
- <sup>127</sup> 5.) Evaluate on held-out possessions
- <sup>128</sup> 6.) Compare to LLM prompting baseline

<sup>130</sup> Given a sequence of play-by-play events within  
<sup>131</sup> a possession, the task is to predict the next labeled  
<sup>132</sup> event from a fixed set of action classes. Each event  
<sup>133</sup> is associated with game context (e.g., time  
<sup>134</sup> remaining, score margin), player participation, and  
<sup>135</sup> on-court lineup configuration. The model observes  
<sup>136</sup> information available up to time  $t$  and predicts the  
<sup>137</sup> next event label at time  $t + 1$ . All events are  
<sup>138</sup> mapped into a standardized action label space  
<sup>139</sup> (Section 2.3) to support multi-class classification

## <sup>140</sup> **2.2 Dataset, Preprocessing and Feature Engineering**

<sup>142</sup> We use NBA play-by-play logs from the 2000–  
<sup>143</sup> 2001 season, obtained from Sports-Statistics.com  
<sup>144</sup> [Sports-Statistics.com, n.d.]. The dataset contains  
<sup>145</sup> event-level records including timestamps, event  
<sup>146</sup> types, team identifiers, and player participation  
<sup>147</sup> fields, which enable reconstruction of possession  
<sup>148</sup> sequences and on-court lineups. From these logs,  
<sup>149</sup> we construct possession-level sequences and  
<sup>150</sup> define next-event prediction as a 12-class  
<sup>151</sup> classification problem.

<sup>152</sup> Because play-by-play logs do not provide full  
<sup>153</sup> tracking trajectories, we focus on information  
<sup>154</sup> consistently available in event metadata and lineup  
<sup>155</sup> structure. To represent the game state at each event,  
<sup>156</sup> we construct graph snapshots with node features  
<sup>157</sup> that combine (1) learned embeddings for high-

<sup>158</sup> cardinality identities (e.g., Player ID) and (2)  
<sup>159</sup> engineered contextual features derived from play-  
<sup>160</sup> by-play context (e.g., time remaining, score  
<sup>161</sup> margin, possession progress). This hybrid  
<sup>162</sup> representation is motivated by prior work using  
<sup>163</sup> GNN and attention-based methods for sports  
<sup>164</sup> prediction, where learned embeddings capture  
<sup>165</sup> entity-level tendencies while structured features  
<sup>166</sup> encode context and temporal state [Zhang, 2020;  
<sup>167</sup> Luo & Krishnamurthy, 2023; Zhao et al., 2025].

<sup>168</sup> *(i) Possession Segmentation:* Each game is  
<sup>169</sup> segmented into possessions using event-type  
<sup>170</sup> heuristics and period boundaries. Much as how  
<sup>171</sup> texts are the building blocks for sentences, it makes  
<sup>172</sup> sense to divide games into possessions, so the  
<sup>173</sup> model can learn structure and what happens in a  
<sup>174</sup> real game.

<sup>175</sup> *(ii) Lineup Reconstruction:* For each event, the full  
<sup>176</sup> on-court lineup was attempted to be reconstructed,  
<sup>177</sup> yielding a fixed set of ten player nodes per graph  
<sup>178</sup> snapshot. When subs are called in, they are  
<sup>179</sup> replaced in the lineup. If possessions had

180 incomplete or ambiguous lineups, they were 230  
181 excluded from graph construction.

182 (iii) *Player Embeddings*: Each player is  
183 represented by a learned embedding that captures  
184 individual tendencies across games and contextual  
185 situations.

186 (iv) *Role Indicators*: Role features are included to  
187 identify the primary, secondary, and tertiary  
188 participants involved in each event.

189 (v) *Offense–Defense Encoding*: Each node  
190 includes an offense–defense indicator derived from  
191 possession context, enabling differentiation of  
192 player roles conditioned on team control.

193 (vi) *Contextual Game Features*: Normalized  
194 temporal and score-related features are  
195 incorporated, including time remaining, score  
196 margin, event tempo, and possession progress.

197 (vii) *Event History Encoding*: A fixed-length  
198 history of recent event types preceding the current  
199 action is embedded to capture short-term temporal  
200 dependencies.

201 (viii) *Data Sanitization*: All features are sanitized to  
202 prevent numerical instability, and graph snapshots  
203 with inconsistent dimensions are discarded.

204 (ix) *Supervision Structure*: Each event is  
205 represented as an independent graph snapshot,  
206 enabling event-level supervision while preserving  
207 the underlying multi-agent structure

### 208 2.3 Label Space

209 In the original NBA play-by-play dataset, events  
210 are mapped to 13 distinct action labels, including  
211 made field goal, missed shot, turnover, timeout,  
212 jump ball, etc. During graph construction and  
213 next-action labeling, the jumpball class was  
214 systematically removed. Although jump balls can  
215 occur during live play (e.g., held-ball situations),  
216 they do not appear as next-action prediction targets  
217 in our dataset. This is because jump balls function  
218 primarily as possession-resolution events rather  
219 than strategic decisions and are absorbed into the  
220 possession initialization and segmentation logic.

221 As a result, jump balls almost never constitute  
222 the next labeled action following a modeled game  
223 state. The “other” category in our label set captures  
224 infrequent, administrative, or ambiguous events  
225 that appear in the play-by-play but do not  
226 correspond to a well-defined basketball decision.  
227 Ultimately, the final prediction task uses 12 action  
228 labels, focusing only on events that meaningfully  
229 represent player or team decision-making.

### 230 2.4 Graph Construction

231 During graph construction, each play-by-play  
232 event within a possession is represented as an  
233 event-level interaction graph capturing the on-  
234 court configuration and game context at that  
235 moment. For each event, we construct a graph  
236  $G_t = (V, E)$  where the node set  $V$  contains exactly  
237 ten nodes, corresponding to the ten players on the  
238 court (5 offensive and 5 defensive), identified via  
239 reconstructed lineups from starting lineups and  
240 substitution logs.

241 We adopt a player-only graph design because  
242 players are the primary decision-making agents in  
243 basketball and are consistently identifiable in play-  
244 by-play data, whereas other potentially useful  
245 entities (e.g., the ball, spatial tracking states, or  
246 explicit defender assignments) are not reliably  
247 available in the dataset. Although richer  
248 heterogeneous graph representations are possible  
249 (e.g., including event nodes, ball nodes, or  
250 possession-level state nodes), this design focuses  
251 on the most stable and directly observable multi-  
252 agent structure.

253 Edges are added between all pairs of players,  
254 producing a fully connected interaction graph. This  
255 choice supports message passing among all  
256 teammates and opponents without requiring  
257 incomplete spatial or matchup annotations and  
258 allows the GAT to learn which player-to-player  
259 interactions are most relevant through attention  
260 weights. Events with missing or unreliable on-  
261 court lineup information are excluded to maintain  
262 consistency and data quality.

### 263 2.5 Node and Edge Features

264 Because player identity is a high-cardinality  
265 categorical variable, we represent each player  
266 using a learned embedding vector rather than one-  
267 hot encoding. This choice allows the model to learn  
268 compact representations of individual tendencies  
269 and roles across game contexts and is consistent  
270 with prior sports prediction work that combines  
271 entity embeddings with attention-based relational  
272 modeling [Zhang, 2020; Luo & Krishnamurthy,  
273 2023]. To incorporate both identity and context, the  
274 final node feature vector is formed by  
275 concatenating learned embeddings with engineered  
276 contextual features, including role indicators,  
277 offense–defense status, normalized game context  
278 variables, and short-term event history. One-hot  
279 features are cast to floating-point tensors, and

280 numeric variables are normalized prior to 332 adaptively emphasize relevant player-to-player  
281 concatenation to ensure stable training. 333 relationships.

282 Each node represents a player on the court, and 334 **2.6 Graph Attention Network**  
283 is associated with a feature vector that combines 335 Each interaction graph is processed using a  
284 player embeddings and contextual signals. 336 multi-layer Graph Attention Network (GAT). The  
285 Specifically, each node consists of: 337 GAT architecture applies masks to self-attention  
286 • A 128-dimensional learned player 338 over neighboring nodes, enabling each player  
287 embedding, capturing player-specific 339 representation to aggregate information from all  
288 tendencies 340 other players on the court while learning which  
289 • A 3-dimensional role indicator denoting 341 interactions are most relevant for the current game  
290 whether the player is directly involved in the 342 state  
291 current event 343 The model uses three stacked GAT layers, each  
292 • A 2-dimensional offense/defense indicator, 344 followed by layer normalization and a non-linear  
293 specifying whether the player is on the 345 activation function. Multi-head attention is  
294 offensive or defensive team for the current 346 employed to stabilize training and capture diverse  
295 possession. 347 patterns of player-to-player interaction. After  
296 • A 6-dimensional game context feature 348 message passing, node embeddings are aggregated  
297 which includes time remaining, score 349 via global mean pooling to produce a  
298 margin, and momentum-related signals 350 fixed-dimensional graph-level representation.  
299 derived from the previous event. 351 This pooled embedding is passed through a  
300 • An 8-dimensional learned event-type 352 feedforward classification head to predict the next  
301 embedding, so that the model can learn that 353 action in the possession. Training is performed  
302 some events are closer to others (like a 354 using cross-entropy loss over a 12-class action  
303 missed field goal and a made field goal are 355 space, with gradient clipping and learning-rate  
304 both shot attempts, and a foul and a free 356 scheduling applied to ensure stable optimization.  
305 throw are closely related) 357 Overall, the architecture encodes strong  
306 • A 9-dimensional event history that encodes 358 relational inductive biases, allowing the model to  
307 the 3 most recent sequence of event types 359 reason about coordinated multi-agent behavior and  
308 within the possession. 360 structured player interactions

309 • A 1-dimensional tempo feature, providing a 361 **2.7 LLM Baseline**  
310 lightweight proxy for game flow and 362 To contextualize GAT’s performance, we  
311 allowing the model to distinguish between 363 introduce a Large Language Model (LLM)  
312 actions occurring in rapid succession versus 364 baseline that operates directly on textual play  
313 those following extended stoppages. 365 descriptions. The LLM is prompted with a short  
314 • A 1-dimensional possession progress vector 366 natural-language summary of the current game  
315 that indicates the relative progression of the 367 state—including time remaining, score margin, and  
316 possession. 368 the most recent play-by-play entry—and is asked  
317 • A 3-dimensional rolling-form vector that 369 to predict the next action from the same label set  
318 captures recent shooting efficiency and 370 used by the GAT model. We evaluate both zero-  
319 usage 371 shot and few-shot prompting strategies. In the zero-  
320 • A 1-dimensional player load feature, which 372 shot setting, the model receives only task  
321 tries to approximate how tired the player is 373 instructions and the current play description. In the  
322 given the minutes that the player has played 374 few-shot setting, the prompt additionally includes  
323 since their last substitution. 375 a small number of labeled example sequences to  
324 All features are concatenated into a fixed-length 376 guide the model’s predictions. The LLM’s textual  
325 node representation and normalized to avoid 377 outputs are then parsed and mapped to the  
326 numerical instability. 378 predefined action labels, enabling direct  
327 Edges connect all pairs of players on the 379 comparison with the GAT’s predictions. This  
328 court. In this project, edges do not carry explicit 380 baseline serves as a lightweight, unstructured  
329 features; instead, the Graph Attention Network 381 alternative that does not explicitly model player  
330 learns weighted interactions implicitly through  
331 attention coefficients, allowing the model to

382 identities, interactions, or spatial relationships. 431 Possession-level splitting therefore evaluates the  
383 Comparing its performance to the GAT highlights 432 model’s ability to make conditional, event-level  
384 the advantages of explicit relational modeling for 433 predictions while avoiding temporal leakage.  
385 fine-grained decision prediction in multi-agent  
386 sports environments.

## 387 2.8 Training and Optimization

388 For training and optimization, the model uses  
389 cross-entropy loss over the action label space.  
390 Training initially uses an unweighted cross-entropy  
391 objective with label smoothing. To improve  
392 performance on rare action classes, a  
393 class-weighted cross-entropy variant is later  
394 introduced, but without label smoothing to avoid  
395 conflicting regularization effects.

396 Training is performed with the Adam optimizer  
397 with decoupled weight decay. To improve stability  
398 during early training, a linear warm-up schedule is  
399 applied over the first several epochs, followed by  
400 cosine annealing for the remainder of training. This  
401 schedule helps mitigate optimization instability  
402 caused by large initial gradients in deep attention  
403 layers.

404 Mini-batches of graphs were constructed using  
405 PyTorch Geometric’s batching mechanism.  
406 Gradients are clipped to a fixed maximum norm to  
407 prevent exploding gradients, which is particularly  
408 important when stacking multiple graph attention  
409 layers. When supported by Google Colab’s GPU,  
410 mixed-precision training is used to accelerate  
411 convergence and reduce memory consumption  
412 without compromising numerical stability.

413 Model performance is monitored on a held-out  
414 validation set at the end of each epoch. Early  
415 stopping is applied based on validation accuracy,  
416 and the checkpoint with the best validation  
417 performance is selected for final evaluation. All  
418 reported metrics are computed using this  
419 best-performing model.

## 420 2.9 Dataset Splits and Evaluation

421 The dataset is split at the possession level,  
422 assigning all graph instances derived from the same  
423 possession to the same split. This choice aligns  
424 with the model design: each graph represents a  
425 self-contained snapshot that does not depend on  
426 future possessions or long-horizon game context. A  
427 game-level split would further prevent player and  
428 team overlap across splits; however, the focus here  
429 is event-level decision modeling rather than  
430 generalization across entire games.

## 434 3 Experiments and Results

435 In this section, we evaluate the proposed Graph  
436 Attention Network (GAT) for next-action  
437 prediction in basketball possessions and compare  
438 its performance to a zero-shot Large Language  
439 Model (Mistral 7B) baseline. The overall  
440 performance is reported per-class performance is  
441 analyzed using confusion matrices.

442 Overall Performance is assessed using Top-1  
443 accuracy, Top-3 accuracy, and macro-averaged F1  
444 score. Top-1 accuracy measures the proportion of  
445 graphs for which the highest-probability prediction  
446 matches the ground-truth next action. Top-3  
447 accuracy evaluates whether the correct label  
448 appears among the three most probable predictions,  
449 offering a more permissive measure of predictive  
450 usefulness in ambiguous game contexts. Macro F1  
451 accounts for class imbalance by weighing all action  
452 classes equally.

453 Beyond aggregate metrics, per-class  
454 performance is analyzed through confusion  
455 matrices, which capture class-specific precision  
456 and recall behavior across both frequent and rare  
457 actions. All results correspond to the best-  
458 performing model checkpoint selected based on  
459 validation accuracy. For comparison, both the  
460 proposed Graph Attention Network and the zero-  
461 shot Large Language Model baseline are evaluated  
462 under the same protocol and action label space.

### 463 3.1 Overall Performance

464 The Graph Attention Network (GAT) achieves  
465 the strongest overall performance, obtaining the  
466 highest Top-1 accuracy, Top-3 accuracy, and  
467 macro-averaged F1 score. These results indicate  
468 that explicitly modeling player interactions and  
469 game structure enables more effective next-action  
470 prediction than relying on LLMs alone.  
471 Incorporating relational inductive biases appears  
472 essential for capturing the dynamics of multi-agent  
473 basketball environments. Across loss formulations,  
474 the GAT trained with label smoothing attains the  
475 highest overall accuracy, while the class-weighted  
476 cross-entropy variant yields slightly lower Top-1  
477 accuracy but a higher macro-averaged F1 score.  
478 This tradeoff reflects improved performance on  
479 infrequent event classes—such as ejections and  
480 timeouts—which, although not strictly on-ball

481 actions, remain meaningful next-event outcomes.  
 482 Class weighting therefore helps mitigate class  
 483 imbalance by encouraging the model to allocate  
 484 more capacity to rare actions.

485 In contrast, the LLM baselines exhibit  
 486 substantially lower accuracy and macro-F1 scores,  
 487 demonstrating difficulty in predicting fine-grained  
 488 next actions from textual play descriptions alone.  
 489 Few-shot prompting provides modest  
 490 improvements over the zero-shot setting, but the  
 491 gains remain limited and fall well short of the  
 492 structured GAT models. Overall, these findings  
 493 highlight the limitations of unstructured sequence  
 494 models for event-level prediction and reinforce the  
 495 value of explicit relational modeling.

### 496 3.2 Per-Class Performance

497 To contextualize model performance, we  
 498 include a simple frequency-based baseline that  
 499 always predicts the most common next-action  
 500 label. Because it ignores player identities,  
 501 contextual cues, and interaction structure, this  
 502 baseline quantifies how much predictive power can  
 503 be attributed solely to class imbalance.

504 A per-class analysis reveals clear differences in  
 505 how each model handles frequent versus rare  
 506 basketball events (Appendix Figures A1–A4). The  
 507 GAT trained with class-weighted loss (Figure A2)  
 508 improves recall for structurally constrained and  
 509 low-frequency actions—such as timeouts,  
 510 substitutions, violations, and ejections—by  
 511 redistributing probability mass away from  
 512 dominant classes. This prevents the model from  
 513 collapsing onto the most common outcomes and  
 514 yields a more balanced error profile.

515 The label-smoothed GAT (Figure A1), by  
 516 contrast, achieves the highest overall Top-1 and  
 517 Top-3 accuracy due to strong discrimination  
 518 among high-frequency on-court actions (made  
 519 shots, missed shots, rebounds, free throws).  
 520 However, smoothing reduces sensitivity to rare  
 521 events, leading to systematic misclassification of  
 522 administrative or off-ball actions as more common  
 523 possession-level events.

524 The LLM baselines (Figures A3–A4) exhibit a  
 525 qualitatively different pattern. Zero-shot prompting  
 526 shows a strong tendency to predict the “other”  
 527 category and struggles to separate fine-grained  
 528 basketball actions. Few-shot prompting modestly  
 529 improves recall for majority classes but does not  
 530 meaningfully improve macro-F1, and the LLM

Model	Top 1	Top 3	Macro F1
Majority-class baseline	0.2400	-	-
GAT (smoothing)	0.5198	0.8671	0.3934
GAT (weighted class)	0.4587	0.8049	0.3948
Mistral (Zero Shot)	0.0786	0.0856	0.0985
Mistral (Few Shot)	0.0779	0.1133	0.0462

Table 1: Comparison of next-action prediction performance across GAT models trained with class-weighted loss and cross-entropy with label smoothing, alongside zero-shot and few-shot LLM baselines. A frequency-based baseline model is also included for reference. Metrics reported include Top-1 accuracy, Top-3 accuracy, and macro-averaged F1.

531 rarely predicts rare actions such as violations or  
 532 ejections even when contextual cues are explicit.

## 533 4 Discussion

534 The performance differences across models can  
 535 be understood through the lens of inductive bias,  
 536 representation structure, and class imbalance.  
 537 While all models operate over the same action label  
 538 space, they differ fundamentally in how they  
 539 encode game state and how they allocate  
 540 probability mass across frequent and rare events.

### 541 4.1 Inductive Bias vs. Language Modeling

542 The central finding of this work is the clear  
 543 advantage of models that encode explicit relational  
 544 structure. The GAT consistently outperforms both  
 545 zero-shot and few-shot LLM baselines,  
 546 demonstrating the value of inductive bias for  
 547 next-action prediction. By representing each  
 548 possession as a graph over the ten players on the  
 549 floor, the GAT conditions its predictions on player  
 550 identity, team membership, offensive and  
 551 defensive roles, and recent interaction patterns.  
 552 This structured representation allows the model to  
 553 reason about who is involved in the play and how  
 554 prior actions constrain the set of plausible next  
 555 events.

556 LLMs, in contrast, operate over linearized  
 557 play-by-play text that compresses these  
 558 dependencies into a sequence of tokens. Although  
 559 the text captures narrative flow, it does not  
 560 explicitly encode lineup configuration, possession  
 561 boundaries, or role-specific interactions. As a  
 562 result, LLMs struggle with state-dependent or  
 563 rule-driven events—such as substitutions,  
 564 free-throw sequences, and possession changes—  
 565 that require precise modeling of game transitions.  
 566 These limitations highlight that next-action

567 prediction in basketball is fundamentally a relational reasoning task, and that models with explicit multi-agent structure hold a decisive advantage over language-only approaches.

## 571 4.2 Rare Events and Class Imbalance

572 The comparison between training objectives reveals meaningful tradeoffs in how the GAT handles class imbalance. Class-weighted cross-entropy improves macro-F1 by increasing recall for rare but structurally important actions such as ejections, timeouts, and violations.

573 Reweighting encourages the model to devote capacity to these sparse outcomes rather than collapsing into majority classes.

574 Label smoothing, by contrast, improves overall Top-1 accuracy by tempering overconfidence on frequent actions like made shots, missed shots, and rebounds.

575 However, this comes at the cost of rare-event sensitivity: the smoothed model more

576 often misclassifies administrative or off-ball events as common possession-level actions. These patterns reflect the inherent difficulty of predicting events that are weakly signaled by player interactions. While shots and rebounds have strong relational cues, events like timeouts or ejections depend on external factors such as coaching decisions or officiating. The improved performance of the weighted GAT suggests that combining explicit structural modeling with targeted loss weighting can partially offset this sparsity and enhance recognition of rare but meaningful actions.

## 599 4.3 What the Model Is Actually Learning

600 The GAT model is not learning which player is most likely to take the next shot. Rather, it captures higher-level patterns of game flow conditioned on the multi-agent layout on the court. This includes identifying the current possessions, anticipating administrative transitions, and modeling how recent events constrain the set of plausible next actions. Contextual features such as score margin, time remaining, and possession progress further allow the model to adapt its predictions to situational factors that shape decision-making.

611 The contrast between administrative and on-court actions provides additional insight into the model’s behavior. On-court actions—shots, rebounds, turnovers—are tightly coupled to player interactions and spatial relationships, and the GAT predicts them with relatively high accuracy.

617 Administrative actions such as timeouts, substitutions, and ejections are less directly observable from player dynamics, yet they still benefit from explicit graph structure and class-weighted training. The model’s ability to recover these events, despite their weak on-court

623 signatures, highlights the value of incorporating relational and contextual cues.

625 Overall, the GAT demonstrates an ability to reason about basketball as a coordinated multi-agent system rather than a sequence of isolated events. By attending over player embeddings and interaction context, the model captures how collective behavior evolves throughout a possession. These findings reinforce

632 the importance of relational inductive biases for modeling complex, structured decision processes in sports environments.

## 635 Limitations

636 While the proposed graph-based framework demonstrates strong performance on next-action prediction in basketball, several limitations remain.

639 The approach depends heavily on the accuracy and consistency of NBA play-by-play annotations, which can contain ambiguities, season-to-season inconsistencies, and occasional missing or delayed events. Administrative actions such as ejections or timeouts are only loosely connected to on-court interactions, meaning that errors or omissions in the underlying logs propagate directly into graph construction and labeling.

648 A second limitation arises from the heuristic reconstruction of on-court lineups and possessions. Lineups are inferred from substitution patterns and early-game participation, a procedure that works well for most possessions but can fail in edge cases involving incomplete substitution records or corrupted game segments. Possessions for which lineups cannot be reliably reconstructed are excluded, introducing a mild selection bias toward cleaner, more complete data.

658 The model also lacks explicit spatial information. Because it operates solely on play-by-play text rather than player-tracking data, the GAT reasons about interactions and roles abstractly rather than geometrically. This design choice enables broad applicability but limits the model’s ability to capture fine-grained tactical patterns such as defensive spacing, shot contesting, or off-ball movement.

667 Class imbalance further poses challenges. Even  
668 with weighted loss functions, rare events such as  
669 ejections and violations remain difficult to predict,  
670 in part because they depend on contextual factors  
671 external to player interactions, including officiating  
672 decisions. Although class weighting improves  
673 recall for these events, overall performance  
674 remains limited, underscoring the inherent  
675 difficulty of modeling low-frequency  
676 administrative actions.

677 Finally, the LLM baseline is intentionally  
678 simplified. It relies only on zero-shot and few-shot  
679 prompting of an off-the-shelf model, without  
680 fine-tuning, retrieval augmentation, or structured  
681 decoding. As a result, the reported LLM  
682 performance should be interpreted as a lower  
683 bound on what language-based approaches might  
684 achieve with more extensive adaptation. Moreover,  
685 although the dataset spans multiple seasons,  
686 evaluation is conducted on held-out games rather  
687 than entirely unseen seasons or rule regimes,  
688 leaving open questions about generalization across  
689 shifts in league style, officiating emphasis, or roster  
690 composition.

## 691 Conclusion and Future Work

692 This study demonstrates that next-action  
693 prediction in basketball benefits substantially from  
694 structured, interaction-aware modeling. By  
695 encoding each possession as a graph over the ten  
696 on-court players and incorporating contextual  
697 game information, the Graph Attention Network  
698 captures relational dependencies and short-term  
699 game flow that remain inaccessible to  
700 sequence-only language models. The resulting  
701 performance gains, particularly on structurally  
702 constrained and infrequent actions, highlight the  
703 importance of relational inductive biases for  
704 event-level prediction in multi-agent sports  
705 environments.

706 Future research may extend this framework by  
707 evaluating generalization across unseen seasons,  
708 integrating spatial tracking data to capture  
709 fine-grained tactical behavior, or exploring hybrid  
710 architectures that combine graph-based  
711 representations with pretrained language models.  
712 Such directions offer promising avenues for  
713 advancing predictive modeling, simulation, and  
714 decision-support tools within sports analytics.

## 715 Acknowledgements

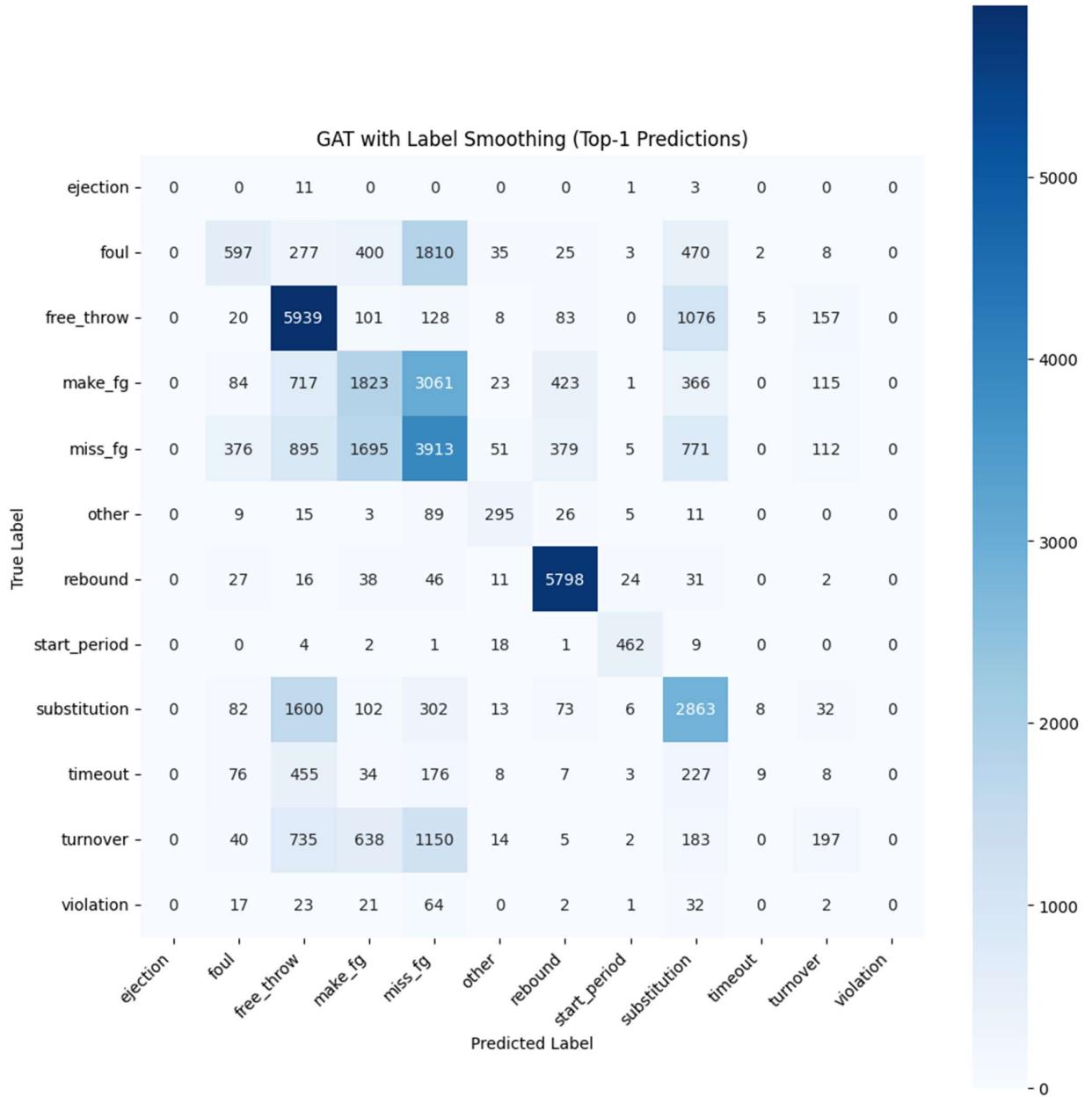
716 I want to thank Professor Zhou Zhang for his  
717 guidance and feedback on this project.

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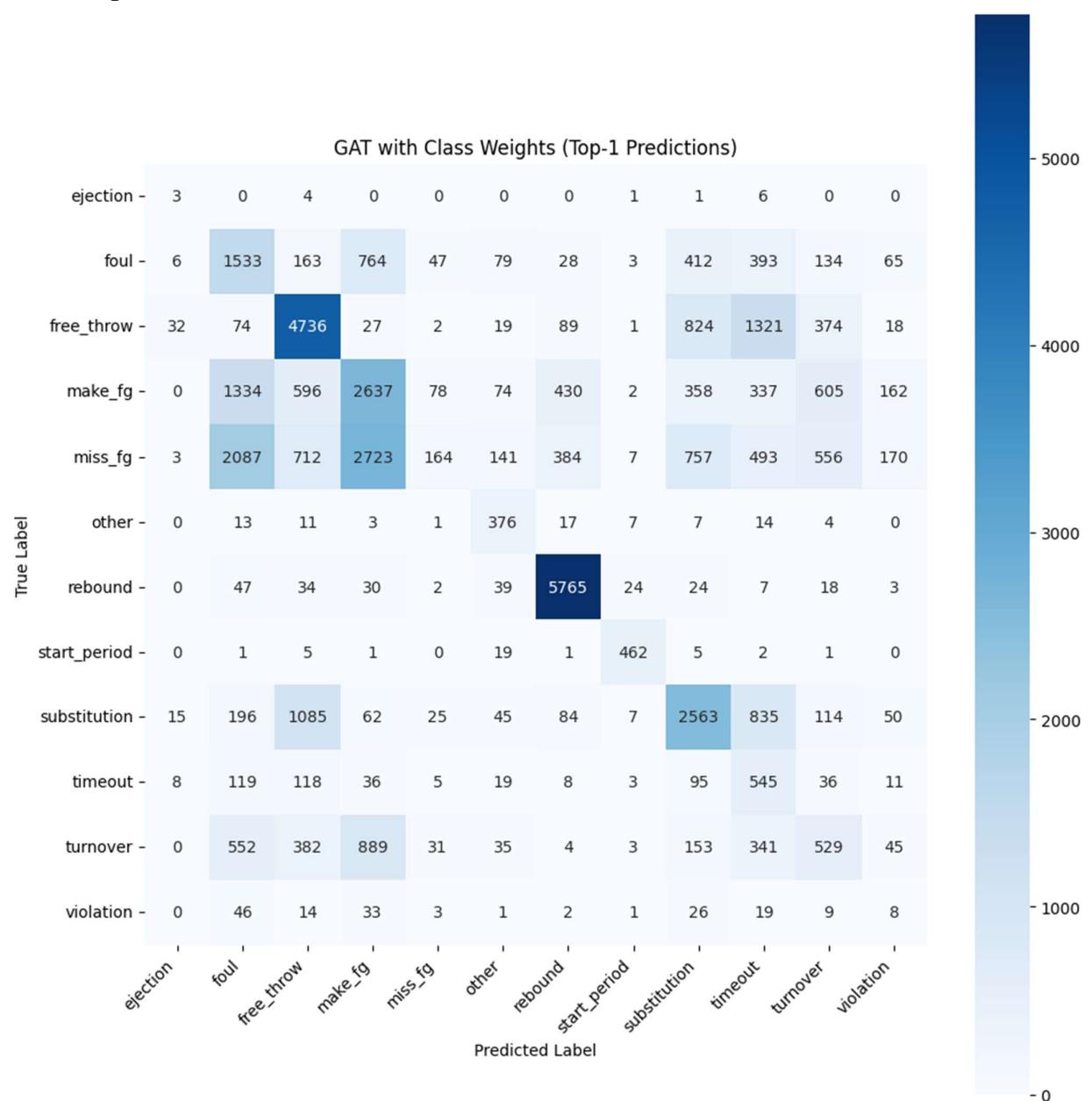
758 **Appendix**

759 **Figure A1. Confusion Matrix for GAT with**  
 760 **Label Smoothing**



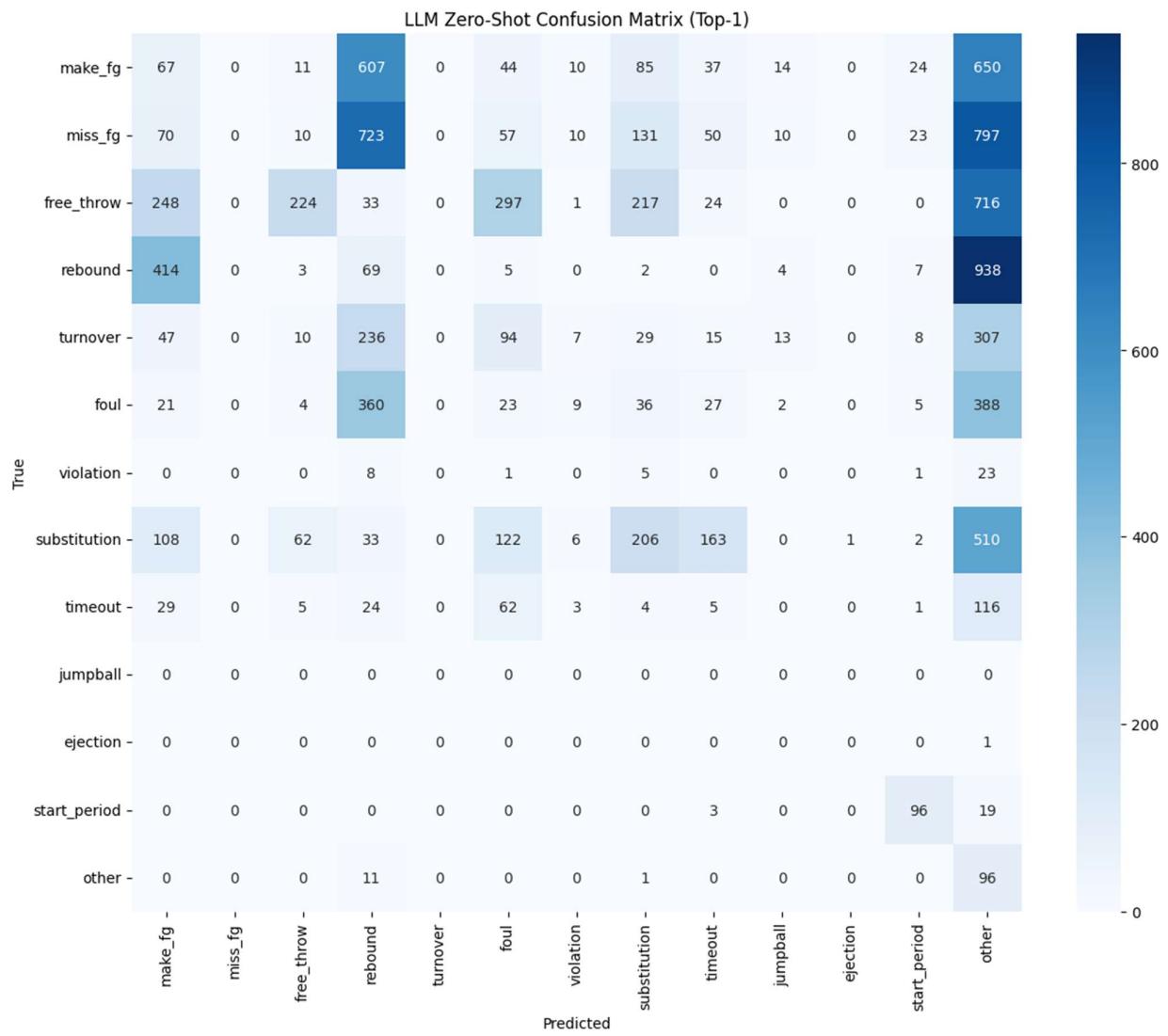
761

<sup>762</sup> **Figure A2. Confusion Matrix for GAT with  
763 Class Weights**



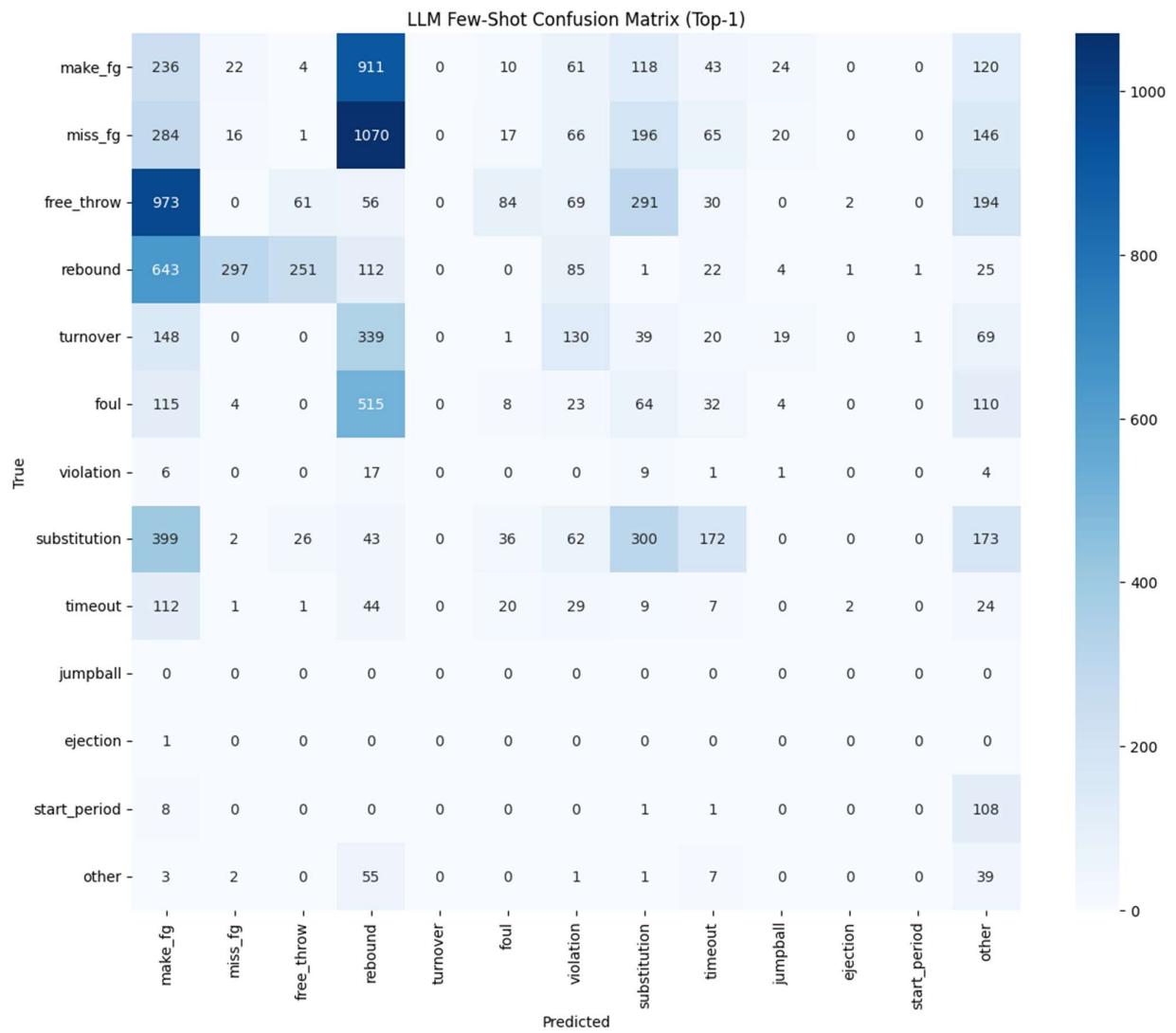
<sup>764</sup> **Figure A3: Confusion Matrix for Mistral 7B**

<sup>765</sup> **Zero-Shot**



766

767 **Figure A4: Confusion Matrix for Mistral 7B**  
 768 **(Few-Shot)**



769

770 **Figure A5: Example Label Space**

	HOMEDESCRIPTION	VISITORDESCRIPTION	NEUTRALDESCRIPTION	EVENTMSGTYPE	EVENTMSGACTIONTYPE	SCORE	POSSESSION_ID
0	NaN	NaN	NaN	12	0	NaN	1
1	Jump Ball Camby vs. Ratliff: Tip to Houston	NaN	NaN	10	0	NaN	2
2	MISS Sprewell 6' Jump Shot	Ratliff BLOCK (1 BLK)	NaN	2	1	NaN	2
3	NaN	76ers Rebound	NaN	4	0	NaN	3
4	Camby S.FOUL (P1.T1)	NaN	NaN	6	2	NaN	3
5	NaN	Ratliff Free Throw 1 of 2 (1 PTS)	NaN	3	11	1 - 0	3
6	NaN	MISS Ratliff Free Throw 2 of 2	NaN	3	12	NaN	3
7	Ward REBOUND (Off:0 Def:1)	NaN	NaN	4	0	NaN	4
8	NaN	Ratliff S.FOUL (P1.T1)	NaN	6	2	NaN	4
9	Camby Free Throw 1 of 2 (1 PTS)	NaN	NaN	3	11	1 - 1	4
10	Camby Free Throw 2 of 2 (2 PTS)	NaN	NaN	3	12	1 - 2	4
11	NaN	MISS Iverson 20' Jump Shot	NaN	2	1	NaN	5
12	Camby REBOUND (Off:0 Def:1)	NaN	NaN	4	0	NaN	6
13	MISS Houston 15' Jump Shot	NaN	NaN	2	1	NaN	6
14	Ward REBOUND (Off:1 Def:1)	NaN	NaN	4	0	NaN	6
15	Ward Bad Pass Turnover (P1.T1)	NaN	NaN	5	1	NaN	6
16	NaN	MISS Hill 10' Jump Shot	NaN	2	1	NaN	7
17	Sprewell REBOUND (Off:0 Def:1)	NaN	NaN	4	0	NaN	8
18	MISS Sprewell 14' Jump Shot	NaN	NaN	2	1	NaN	8
19	NaN	Lynch REBOUND (Off:0 Def:1)	NaN	4	0	NaN	9
20	NaN	Ratliff Layup (3 PTS) (Lynch 1 AST)	NaN	1	5	3 - 2	9
21	Houston 16' Jump Shot (2 PTS) (Ward 1 AST)	NaN	NaN	1	1	3 - 4	10
22	NaN	Ratliff Traveling Turnover (P1.T1)	NaN	5	4	NaN	11
23	NaN	Snow P.FOUL (P1.T2)	NaN	6	1	NaN	12
24	MISS Johnson Layup	Hill BLOCK (1 BLK)	NaN	2	5	NaN	12
25	NaN	76ers Rebound	NaN	4	0	NaN	13
26	Johnson L.B.FOUL (P1.T2)	NaN	NaN	6	3	NaN	13
27	NaN	Ratliff Slam Dunk (5 PTS) (Lynch 2 AST)	NaN	1	8	5 - 4	13
28	MISS Camby 17' Jump Shot	NaN	NaN	2	1	NaN	14
29	NaN	Iverson REBOUND (Off:0 Def:1)	NaN	4	0	NaN	15

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