## **Table of Contents**

| Pre | eface  | . ix |
|-----|--|------|
| Pa  | rt I. The Basics of Simulation and Synthesis |      |
| 1.  | Introducing Synthesis and Simulation         | 3    |
|     | A Whole New World of ML                      | 4    |
|     | The Domains                                  | . 4  |
|     | Simulation                                   | 5    |
|     | Synthesis                                    | 5    |
|     | The Tools                                    | 6    |
|     | Unity  | 6    |
|     | PyTorch via Unity ML-Agents                  | 8    |
|     | Unity ML-Agents Toolkit                      | 8    |
|     | Unity Perception                             | 9    |
|     | The Techniques                               | 9    |
|     | Reinforcement Learning                       | 10   |
|     | Imitation Learning                           | 11   |
|     | Hybrid Learning                              | 12   |
|     | Summary of Techniques                        | 13   |
|     | Projects                                     | 13   |
|     | Simulation Projects                          | 14   |
|     | Synthesis Projects                           | 14   |
|     | Summary and Next Steps                       | 15   |
| 2.  | Creating Your First Simulation               | 17   |
|     | Everybody Remembers Their First Simulation   | 17   |
|     | Our Simulation                               | 18   |

| Setting Up  | 17   |
|---|--|
| Creating the Unity Project                        | 22   |
| Packages All the Way Down                         | 25   |
| The Environment                                   | 26   |
| The Floor   | 26   |
| The Target  | 28   |
| The Agent   | 29   |
| Starting and Stopping the Agent                   | 32   |
| Letting the Agent Observe the Environment         | 35   |
| Letting the Agent Take Actions in the Environment | 36   |
| Giving the Agent Rewards for Its Behavior         | 37   |
| Finishing Touches for the Agent                   | 38   |
| Providing a Manual Control System for the Agent   | 40   |
| Training with the Simulation                      | 42   |
| Monitoring the Training with TensorBoard          | 45   |
| When the Training Is Complete                     | 46   |
| What's It All Mean?                               | 48   |
| Coming Up Next                                    | 52   |
| Colling Of Next                                   |  |
| 3. Creating Your First Synthesized Data           | 53   |
| Unity Perception                                  | 33   |
| The Process                                       | 54   |
| Using Unity Perception                            | 55   |
| Creating the Unity Project                        | 56   |
| Creating a Scene                                  | 62   |
| Getting the Dice Models                           | 62   |
| A Very Simple Scene                               | 63   |
| Preparing for Synthesis                           | 68   |
| Testing the Scenario                              | 72   |
| Setting Up Our Labels                             | 73   |
| Checking the Labels                               | 75   |
| What's Next?                                      | 76   |
| White Next.                                       |  |
|   | MINISTER A STREET, ST.   |
| Part II. Simulating Worlds for Fun and Profit     |  |
|   | and the second second  |
| 4. Creating a More Advanced Simulation            | 81   |
| Setting Up the Block Pusher                       | The second secon |
| Creating the Unity Project                        | 82   |
| The Environment                                   | 82   |
| The Floor   | 83   |
| The Walls   | 85   |
| The wans  |  |

|    | The Block                                  | 8     |
|----|--|-------|
|    | The Goal                                   | 89    |
|    | The Agent                                  | 92    |
|    | The Environment                            | 98    |
|    | Training and Testing                       | 105   |
| 5. | . Creating a Self-Driving Car              | . 107 |
|    | Creating the Environment                   | 108   |
|    | The Track                                  | 100   |
|    | The Car                                    | 114   |
|    | Setting Up for ML                          | 117   |
|    | Training the Simulation                    | 127   |
|    | Training                                   | 128   |
|    | When the Training Is Complete              | 130   |
| 6. | Introducing Imitation Learning             | 122   |
|    | Simulation Environment                     | 133   |
|    | Creating the Ground                        | 134   |
|    | Creating the Goal                          | 135   |
|    | The Name's Ball, Agent Ball                | 140   |
|    | The Camera                                 | 141   |
|    | Building the Simulation                    | 142   |
|    | Agent Components                           | 143   |
|    | Adding Heuristic Controls                  | 146   |
|    | Observations and Goals                     | 148   |
|    | Generating Data and Training               | 149   |
|    | Creating Training Data                     | 149   |
|    | Configuring for Training                   | 150   |
|    | Begin Training                             | 152   |
|    | Running with Our Trained Model             | 153   |
|    | Understanding and Using Imitation Learning | 153   |
| 7. | Advanced Imitation Learning                | 155   |
|    | Meet GAIL                                  | 155   |
|    | Do What I Say and Do                       | 157   |
|    | A GAIL Scenario                            | 157   |
|    | Modifying the Agent's Actions              | 160   |
|    | Modifying the Observations                 | 162   |
|    | Resetting the Agent                        | 163   |
|    | Updating the Agent Properties              | 164   |
|    | Demonstration Time                         | 164   |
|    | Training with GAIL                         | 165   |

|     | Running It and Beyond                 |                         | 167 |
|-----|---------------------------------------|-------------------------|-----|
| 8.  | Introducing Curriculum Learning       | 120:3 %                 | 169 |
| ٠.  | Curriculum Learning in ML             |                         | 170 |
|     | A Curriculum Learning Scenario        |                         | 172 |
|     | Building in Unity                     |                         | 172 |
|     | Creating the Ground                   |                         | 174 |
|     | Creating the Target                   |                         | 174 |
|     | The Agent                             |                         | 175 |
|     | Building the Simulation               |                         | 175 |
|     | Making the Agent an Agent             |                         | 176 |
|     | Actions                               |                         | 177 |
|     | Observations                          |                         | 181 |
|     | Heuristic Controls for Humans         |                         | 182 |
|     | Creating the Curriculum               |                         | 184 |
|     | Resetting the Environment             |                         | 184 |
|     | Curriculum Config                     |                         | 185 |
|     | Training                              |                         | 189 |
|     | Running It                            |                         | 190 |
|     | Curriculum Versus Other Approaches    |                         | 191 |
|     | What's Next?                          |                         | 193 |
| 9.  | Cooperative Learning                  |                         | 195 |
|     | A Simulation for Cooperation          | Adding Hausaid Controls | 195 |
|     | Building the Environment in Unity     |                         | 196 |
|     | Coding the Agents                     |                         | 205 |
|     | Coding the Environment Manager        |                         | 208 |
|     | Coding the Blocks                     |                         | 214 |
|     | Finalizing the Environment and Agents |                         | 216 |
|     | Training for Cooperation              |                         | 222 |
|     | Cooperative Agents or One Big Agent   |                         | 224 |
| 10. | Using Cameras in Simulations          |                         | 225 |
|     | Observations and Camera Sensors       | Most CATE               | 225 |
|     | Building a Camera-Only Agent          |                         | 227 |
|     | Coding the Camera-Only Agent          |                         | 228 |
|     | Adding a New Camera for the Agent     |                         | 232 |
|     | Seeing What the Agent's Camera Sees   |                         | 234 |
|     | Training the Camera-Based Agent       |                         | 240 |
|     | Cameras and You                       |                         | 241 |
|     |                                       |                         |     |

| 11.  | 1. Working with Python   |            |
|------|--|------------|
|      | Python All the Way Down  | 243        |
|      | Experimenting with an Environment  | 244        |
|      | What Can Be Done with Python?  | 250        |
|      | Using Your Own Environment   | 251        |
|      | Completely Custom Training   | 255        |
|      | What's the Point of Python?  | 257        |
| 12.  | Under the Hood and Beyond  | 259        |
|      | Hyperparameters (and Just Parameters)  | 260        |
|      | Parameters   | 260        |
|      | Reward Parameters  | 261        |
|      | Hyperparameters  | 263        |
|      | Algorithms   | 264        |
|      | Unity Inference Engine and Integrations  | 266        |
|      | Using the ML-Agents Gym Wrapper  | 267        |
|      | Side Channels  | 270        |
| Par  | t III. Synthetic Data, Real Results  |            |
| 13   | Creating More Advanced Synthesized Data  | 275        |
| 13.  | Adding Random Elements to the Scene  | 275        |
|      | Randomizing the Floor Color  | 275<br>276 |
|      | Randomizing the Camera Position  | 278        |
|      | What's Next?   | 282        |
|      | the state of the s |            |
| 14.  | Synthetic Shopping   | 283        |
|      | Creating the Unity Environment   | 283        |
|      | A Perception Camera  | 287        |
|      | Faking It Until You Make It  | 300        |
|      | Using Synthesized Data   | 302        |
| Inde | ex   | 305        |