CS483 Task 4: Deterministic and Nondeterministic Firing Solutions

Description

This task investigates Monte Carlo simulation (also known as stochastic, probabilistic, or nondeterministic), which involves random factors in the execution of the model. It still uses a continuous time-stepped simulation as in the earlier tasks, but now there are unpredictable factors in play, which we are trying to determine and understand. This task is about simulation and analysis. There is relatively little visualization because we are trying to distill a wide range of results down to a few numbers.

This is a classical physics and math problem that was in many respects the impetus for the development of electronic computers. Lecture will cover this in more detail.

The premise is to hit an arbitrary target with a projectile. There are two kinds of projectiles: artillery shells and bombs. Artillery shells are fired by artillery pieces, and bombs are dropped by bomber aircraft. Like the Newtonian physics in Task 3, a very simple model can be incredibly powerful when used in the QMSVA framework. As usual, it is provided so we are all working on the same problem. The simulation is again a skeleton.

We are using a two-dimensional world defined in feet. The x axis is distance from the launch platform on the left to the target on the right. The y axis is altitude.

Specifications

Implement your simulation code in `Simulation`. You may do anything you want in this class. There should be no reason to modify the other classes.

Our measure of success for targeting is a boolean function called Circular Error Probable (CEP). It is satisfied for our purposes if the percentage of hits that land within distance $\pm d$ of the aim point is at least half:

$$\text{CEP}(d) = (\text{num\_hits\_within\_distance\_}d \;/\; \text{num\_shots}) \geq 0.5$$

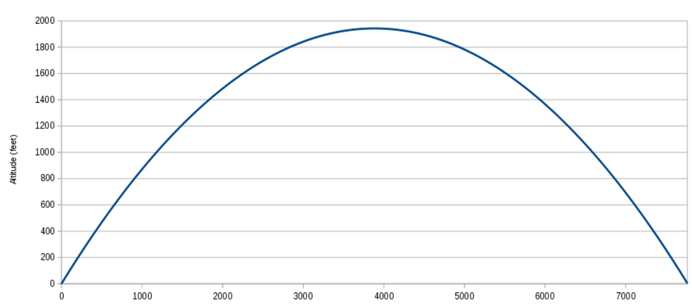
Use a time step of 0.01 seconds unless otherwise stated. Error variation has no specific units, but it relates to the unit it applies to; for example, 10 for elevation is a Gaussian distribution in degrees. Be sure to use a different random seed for each Monte Carlo run.

See the Deliverables section for which parts you need to do. Try to do them in order because later solutions may rely on earlier ones. Each is very small, but there are a lot of them. Start early.

Part I: Artillery

An artillery piece modeled in `Artillery` fires a dumb projectile at a vertical angle (elevation). In our two-dimensional world, the horizontal angle (azimuth) is not considered. Downrange error is the difference on the x axis between the aim point and the impact point. A three-dimensional solution would also have a crossrange error on the horizontally perpendicular axis. These results would be more realistic, but the size of this task would triple.

The projectile has an initial muzzle velocity. It flies in a parabolic arc with no drag effects and impacts the ground at a certain distance after a certain time. For example, 45 degrees at 500 feet per second (fps) produces this flight path:



A. “Clean” Deterministic Solutions

A deterministic solution is mathematically perfect. There is no randomness involved to model errors. Therefore, one run is sufficient to determine its performance. This part is “clean” because the environment introduces no errors. Part E introduces nonrandom wind.

Use firing position (0,0), initial velocity 500 fps, and range to target 5000 feet.

This part is small enough to do by hand, but it is important for the later parts to build a simple control system in your simulation. You know the (distance) range to the target. Loop over a (mathematical) range of elevations until the projectile hits it (give or take). Alternatively, output all the results to Excel and plot them to determine the points of interest by eye.

1. Calculate the elevation to hit a target at the same altitude.
2. Calculate the elevation to hit a target at lower altitude –1000.
3. Calculate the elevation to hit a target at higher altitude +1000.
4. Rerun 1 with time step 0.1 and compare the difference as the error attributed to the time step.
5. Rerun 4 with time step 0.001.

B. Monte Carlo I Solutions: Variable Launch Conditions

The Monte Carlo experiments use randomization to perturb elements of the model as the simulation executes it. This part perturbs the launch conditions of the artillery piece, but the flyout conditions of the munition are perfect.

For 1 through 5, fire 1000 shots each. Return the value that produces a result that satisfies CEP 100. For 1, 2, and 6, the target is 5000 feet away. Initial velocity is 500 fps for all.

1. Calculate the maximum variation in elevation.
2. Calculate the maximum variation in initial velocity.
3. Calculate the maximum range given elevation variation 8.
4. Calculate the maximum range given initial velocity variation 5.
5. Calculate the maximum range given elevation variation 4 and initial velocity variation 4.
6. Calculate how many shots are needed to put 3 within 50 feet of the target with elevation variation 8 and initial velocity variation 5.

C. Monte Carlo II Solutions: Variable Flyout Conditions

This part perturbs the flyout conditions, but the launch conditions are perfect.

Assume the same initial conditions as in Part I.B.

1. Calculate the maximum variation in velocity x.
2. Calculate the maximum variation in velocity y.
3. Calculate maximum range given velocity x variation 2.5.
4. Calculate maximum range given velocity y variation 2.5.
5. Calculate maximum range given velocity x variation 2 and velocity y variation 2.
6. Calculate how many shots are needed to put 3 within 50 feet of the target with velocity x variation 2 and velocity y variation 2.

D. Monte Carlo I and II Solutions: Variable Launch and Flyout Conditions

Monte Carlo I and II are typically not combined for analysis because it is practically impossible to determine which inputs contribute to which outputs (known as confounding variables). However, in the real world, all factors usually combine in insidious ways. This test provides some insight into more realistic performance where both the launch and flyout conditions have random errors.

1. Fire 1,000 shots at 45 degrees of elevation. The elevation variation is 2, initial velocity variation 2, velocity x variation 2, and velocity y variation 2. Report the average error compared to the deterministic solution; i.e., with no variations.

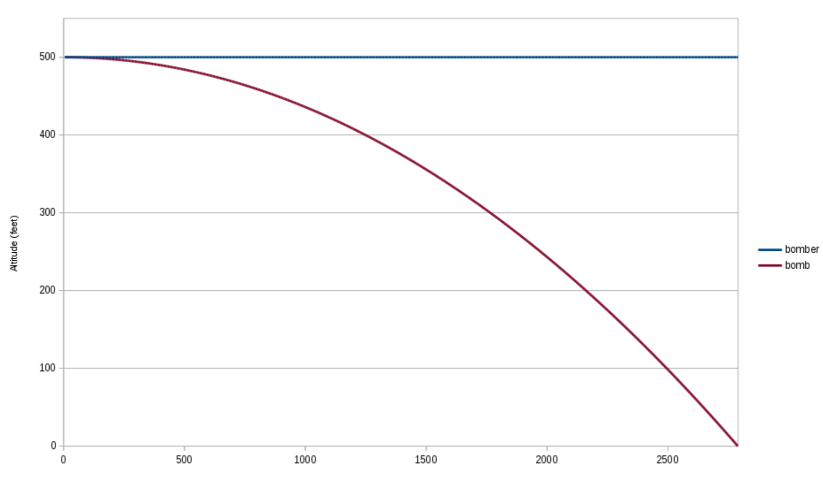
E. "Dirty" Deterministic Solutions: Wind

The deterministic firing solution in Part A had no errors in the artillery piece or munition. Assume this is still the case, but there is now a 15 mph wind in the "dirty" firing environment. Downrange means away from the launcher, upwind toward it. Compare against the clean deterministic solution. For 1–6, show a graph of the expected versus actual flight paths. If it is not too cluttered, all seven can appear on the same graph.

1. Calculate the targeting error when the wind is downrange.
2. Calculate the targeting error when the wind is uprange.
3. Calculate the targeting error when the wind in the lower half of altitude is downrange and there is no wind in the upper half.
4. Calculate the targeting error when the wind in the upper half is downrange and there is no wind in the lower half.
5. Calculate the targeting error when the wind in the lower half is downrange and the upper half is uprange.
6. Calculate the targeting error when the wind in the lower half is uprange and the upper half is downrange.
7. What are your general observations about how this wind affects targeting? Hint: There are six combinations of direction and layer, but you do not need to address each individually.

Part II: Bomber

A bomber modeled in `Bomber` drops a dumb bomb from an altitude with a forward speed at time 0. The projectile maintains this constant forward speed as gravity acts upon it downward (which is unrealistic, but there are no drag effects). It flies in a somewhat half parabolic arc and impacts the ground at a certain distance after a certain time. For example, a bomber at 500 feet going 500 feet per second produces these flight paths:



A. Deterministic Solutions

As with the artillery, a deterministic solution is mathematically perfect. It sets the baseline performance that the Monte Carlo solutions try to achieve.

1. Plot the four combinations of release altitude 500 and 1000 feet and speed 300 and 600 on one graph. What are your general observations?

B. Monte Carlo I Solutions: Variable Release Conditions

This part perturbs the bomber to model variations in the release conditions, but the descent conditions for the bomb are perfect.

Assume the release altitude is 1000 feet at 500 feet per second. The target is 3945 feet away. Measure against CEP 100.

1. Calculate the maximum variation in velocity.
2. Calculate the maximum variation in altitude.
3. Calculate how many bombs are needed to put 5 within 30 feet of the target with velocity variation 10 and altitude variation 10.

C. Monte Carlo II Solutions: Variable Descent Conditions

This part perturbs the bomb to model variations in the descent conditions, but the release conditions are perfect.

Assume the same initial conditions as in Part II.B.

1. Calculate the maximum variation in velocity x.
2. Calculate the maximum variation in velocity y.
3. Calculate how many bombs are needed to put 5 within 30 feet of the target with velocity x variation 15 and velocity y variation 1.5.

D. Monte Carlo I and II Solutions: Variable Release and Descent Conditions

As in Part I.D, this part models a lot of factors simultaneously. It gives a good overview of the performance landscape, but it does not offer much help in the inverse direction to determine what contributed to it.

1. Drop 1,000 bombs from 1,200 feet at 450 miles per hour. The altitude variation is 5, speed variation 5, velocity x variation 5, and velocity y variation 5. Report the average error compared to the deterministic solution.

Deliverables

Do this many tests from each part:

Part	Undergrads	Graduates
I.A	5	5
I.B	2	3
I.C	2	3
I.D	1	1
I.E	2	3
II.A	1	1
II.B	2	3
II.C	2	3
II.D	1	1

Submit the following:

- Your Java code for `Simulation` only. No other code should need changing.
- A nicely formatted PDF document that appropriately indicates the results of each test. Be sure to label each test; e.g., Test III.A.1. Graphs are fine, but not every test needs one.