CS 575 Parallel Programming

Project #2

Functional Decomposition

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Description: This project uses parallel programming to perform a month-by-month simulation of grain growth from the start of 2025 to the end of 2030. The growth of grain is by several factors: the number of deer, the number of wolves (the custom agent I added), and environmental factors (temperature and precipitation). Parallelism allows each thread to handle a specific task of the simulation independently. In this program, three threads are used for computing and updating the number of deer, the number of wolves, and the grain height based on the current state in parallel. An additional thread is used to print the updated state, increment the time, and update environmental variables for the next month. Thus, four threads in total are used to run the simulation, and the simulation was executed on the OSU Flip3 server.

Commentary:

1. **What your own-choice quantity was and how it fits into the simulation?**

   My own-choice quantity is the number of wolves, which are predators of the deer. Due to the prey-predator relationship, there will be a cyclic pattern between the prey (deer) population and the predator (wolf) population: an increase in one will lead to a decrease in the other, and vice versa. I use the classical Lotka-Volterra model to simulate this ecological interaction between the two animal populations. This model describes the prey-predator relationship with two differential equations for the instantaneous rate of change in each population:

   $$\frac{dx}{dt} = \alpha x - \beta xy \quad , \quad \frac{dy}{dt} = \delta xy - \gamma y$$

   where:

   - x is the current size of the prey population (deer). Initial $x = 20$ in this simulation.
   - y is the current size of the predator population (wolves). Initial $y = 5$ in this simulation.
   - α is the growth rate of the prey population. $\alpha = 0.3$ in this simulation

- β is the death rate of the prey population due to predation. $\beta = 0.015$ in this simulation.
- δ is the growth rate of the predator population due to predation. $\delta = 0.01$ in this simulation.
- γ is the decline rate of the predator population. $\gamma = 0.9$ in this simulation.
- dt represents the time interval per generation. In this simulation, dt is one month per generation, but a generation may span several years in the real ecosystem.

Thus, the addition of wolves can provide direct control over the deer population and indirectly influence the growth of grain, since fluctuations in the deer population caused by the predation will vary grazing pressure on the grain.

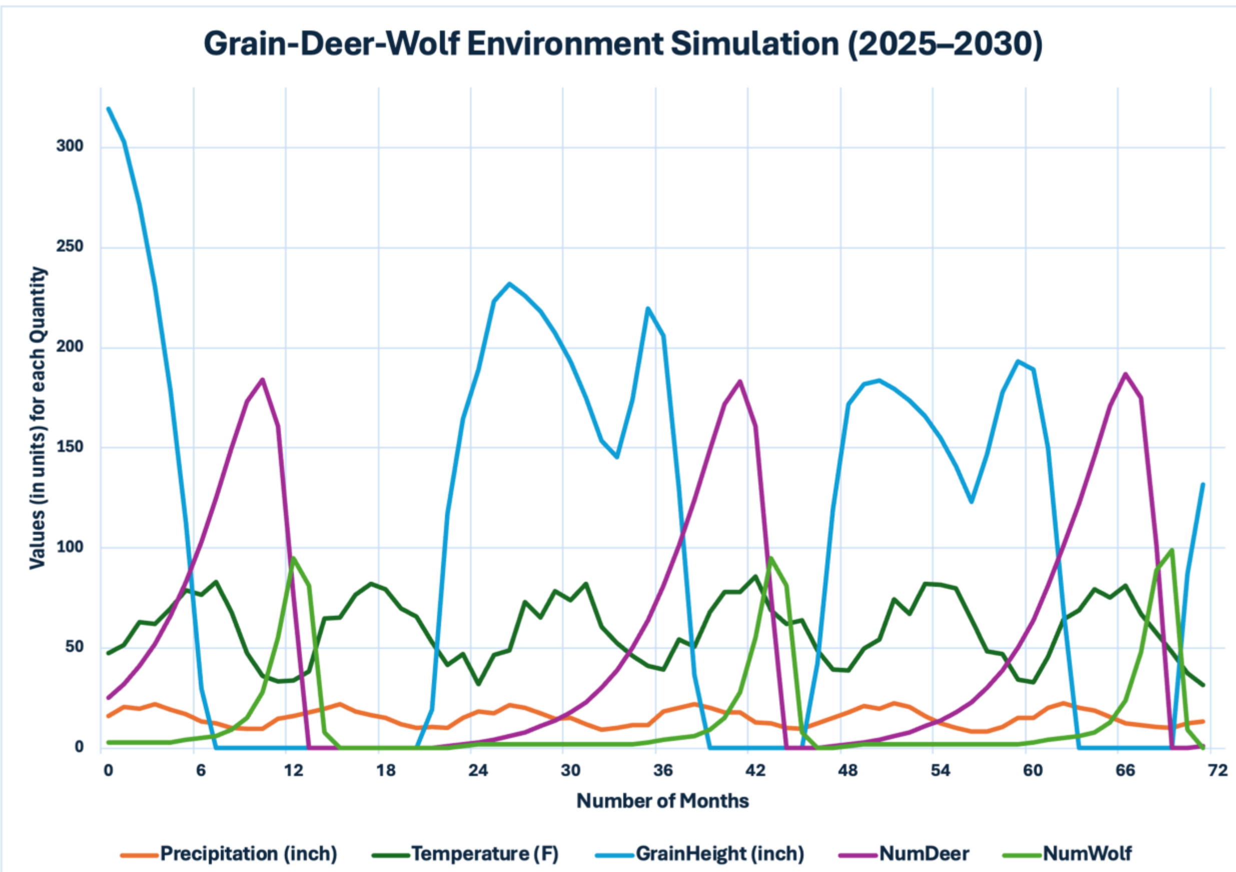
2. **A table showing values for temperature, precipitation, number of deer, height of the grain, and your own-choice quantity as a function of month number.**

Year	Month	Month Number	Precipitation (inch)	Temperature (F)	Height of the Grain (inch)	Num of Deer	Num of Wolves
2025	1	0	16.13	47.49	319.21	25	3
2025	2	1	20.44	51.52	303.14	32	3
2025	3	2	19.59	63.06	271.34	41	3
2025	4	3	21.87	61.88	230.54	52	3
2025	5	4	19.46	69.7	178.55	66	3
2025	6	5	17.07	78.87	112.55	83	4
2025	7	6	13.5	76.61	29.55	103	5
2025	8	7	12.42	83.19	0	125	6
2025	9	8	10.07	67.89	0	150	9
2025	10	9	9.63	47.66	0	173	15
2025	11	10	9.73	36.18	0	184	28
2025	12	11	14.66	33.43	0	161	55
2026	1	12	16.16	33.82	0	76	95
2026	2	13	17.68	38.45	0	0	81
2026	3	14	19.67	64.8	0.08	0	8
2026	4	15	22.15	65.44	0.12	0	0
2026	5	16	18.43	76.39	0.12	0	0
2026	6	17	16.65	82.07	0.12	0	0
2026	7	18	15.34	79.19	0.12	0	0
2026	8	19	11.84	69.99	0.13	0	0
2026	9	20	10.28	65.71	0.27	0	0
2026	10	21	10.77	52.83	**19.44**	0	0
2026	11	22	10.17	41.52	**117.12**	1	0

2026	12	23	15.12	46.84	**164.32**	2	1
2027	1	24	18.35	32.08	188.9	3	2
2027	2	25	17.59	46.38	223.34	4	2
2027	3	26	21.45	48.67	232.06	6	2
2027	4	27	20.19	72.98	226.06	8	2
2027	5	28	17.32	65.43	218.15	11	2
2027	6	29	14.81	78.47	207.15	14	2
2027	7	30	15.33	74.08	193.15	18	2
2027	8	31	12.16	82.19	175.15	23	2
2027	9	32	9.36	60.51	153.64	30	2
2027	10	33	10.25	52.33	**145.5**	39	2
2027	11	34	11.43	46.11	**173.97**	50	2
2027	12	35	11.6	41.31	**219.76**	64	3
2028	1	36	18.28	39.43	205.97	81	4
2028	2	37	20.13	54.47	129.39	101	5
2028	3	38	21.75	50.51	36.72	124	6
2028	4	39	20.21	67.98	0	149	9
2028	5	40	17.91	77.9	0	172	15
2028	6	41	18.07	78.12	0	183	28
2028	7	42	12.77	85.9	0	161	55
2028	8	43	12.33	68.72	0	76	95
2028	9	44	9.95	62.18	0	0	81
2028	10	45	9.56	63.95	**0.32**	0	8
2028	11	46	12.19	49	**42.69**	0	0
2028	12	47	15.14	39.47	**119.24**	1	0
2029	1	48	17.81	38.65	171.58	2	1
2029	2	49	20.89	49.54	181.87	3	2
2029	3	50	19.66	54.47	183.72	4	2
2029	4	51	22.48	74.18	179.72	6	2
2029	5	52	20.77	67.1	173.74	8	2
2029	6	53	16.28	82.14	165.74	11	2
2029	7	54	12.57	81.71	154.74	14	2
2029	8	55	9.99	79.86	140.74	18	2
2029	9	56	8.11	64.12	123.02	23	2
2029	10	57	8.31	48.57	**146.62**	30	2
2029	11	58	10.42	46.99	**177.88**	39	2
2029	12	59	15.07	34.07	**193.29**	50	2
2030	1	60	15.06	32.74	189.03	64	3
2030	2	61	20.28	45.77	149.93	81	4
2030	3	62	22.54	64.52	68.98	101	5
2030	4	63	20.33	68.87	0	122	6

2030	5	64	18.72	79.14	0	146	8
2030	6	65	15.48	75.2	0	171	13
2030	7	66	12.42	81.01	0	187	24
2030	8	67	11.69	67.19	0	175	48
2030	9	68	10.38	57.69	0	101	89
2030	10	69	10.18	48.11	**0**	0	99
2030	11	70	12.56	37.35	**87.31**	0	9
2030	12	71	13.53	31.73	**131.86**	1	0

3. **A graph showing temperature, precipitation, number of deer, height of the grain, and your own-choice quantity as a function of month number.**



4. **A commentary about the patterns in the graph and why they turned out that way. What evidence in the curves proves that your own quantity is actually affecting the simulation correctly?**

Although the generation interval has been shortened to one month for convenience, the simulation results in the above graph show clear cyclic patterns for each quantity that align well with the theoretical ecological patterns:

- ***Precipitation and temperature show a distinct seasonal pattern that matches the real-world weather***. Temperatures are low in winter, rise steadily in spring, peak in summer, and then decline in fall. Precipitation is moderate to high during spring, fall, and winter with a relatively drier summer. Such clear seasonal variations shown in every year of the simulation match the characteristics of the humid continental climate.
- ***Grain growth is directly impacted by temperature, precipitation, and the number of deer***. In this simulation, I set the optimal growth conditions for the grain at 40°F and 10 inches of precipitation (a cool-season crop). We can observe a rapid increase in grain height from November to December during 2026-2030 (highlighted in bold in the table above) when temperature and precipitation are close to the optimal. When environmental conditions deviated a lot from optimal levels in the dry summers of 2027 and 2029, grain growth can be suppressed even under low grazing pressure from the deer population. This also explains the lag in the initiation of the second predator-prey cycle: grazing pressure is low in the spring and summer of 2026, but since grain is a cool-season crop, it begins to grow in the winter of 2026 and then the second cycle is initiated. As the grain grows tall enough, it attracts deer to graze. When the deer population becomes large enough, grain height declines significantly due to increased grazing pressure. This explains why grain growth is halted or suppressed even with the optimal conditions during the winter of 2025.

We can also observe that the addition of wolves in the simulation impacts both the deer population and the growth of grain as expected:

- ***The introduction of the wolf population appropriately produces the expected predator-prey population cycles***. We can observe that the populations of deer and wolves oscillate in a cyclic pattern over the simulation from 2025 to 2030. When the deer population reaches a peak, the wolf population soon increases due to greater prey availability. As predation intensifies, the deer population shrinks. A subsequent decline in the wolf population then occurs once the prey becomes scarce. This cyclical rise and fall occurred nearly three times in these six years, which is consistent with the expectations in the Lotka-Volterra model.
- ***The wolf population indirectly promotes the growth of the grain by controlling deer populations***. When the wolf population is high and the deer population shrinks due to intensified predation near the end of a predator-prey cycle, grain begins to recover and then grows rapidly due to low grazing pressure. Conversely, when the number of wolves is low and the deer population expands quickly, grain growth is suppressed due to increased grazing pressure.