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Department of Computer Science and Engineering

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Even Semester

DESIGN AND ANALYSIS ALGORITHMS (24CS2203)

ALM – PROJECT BASED LEARNING

High-Speed Weather Forecasting via PRAM-Based Parallel Computation

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PROBLEM STATEMENT

The problem of weather forecasting involves predicting atmospheric conditions by processing large-scale meteorological data using computational models.

Given:

- Complex coupled **nonlinear partial differential equations** modelling atmospheric behaviour
- **High dimensional meteorological data** involving variables like temperature, pressure, humidity, wind speed, etc.
- Need for **accurate and timely forecasts** for practical decision-making

Goal:

- Develop **parallel algorithms using the Parallel Random-Access Machine (PRAM)** model to process weather data rapidly
- Decompose **meteorological computations** into **concurrent tasks** suitable for PRAM's shared memory parallelism
- **Reduce overall computation** time while maintaining or improving accuracy of weather forecasts

Challenges:

- Extremely high computational complexity of numerical weather prediction
- Large data volume requiring efficient memory and processing management
- Synchronization and communication overhead between parallel processors
- Handling of dynamic data assimilation and ensemble forecasting

Objectives:

- Understand PRAM architecture and its applicability to weather forecasting algorithms
- Design and implement parallel algorithms for atmospheric equation solving, spectral transformations, and data assimilation
- Analyse time and space complexity benefits of parallel PRAM computation versus serial processing
- Evaluate theoretical speedup and real-world feasibility of PRAM-based weather forecasting

Applications:

- Real-time regional and global weather prediction systems
- Environmental monitoring and disaster preparedness
- Ensemble forecasting used by meteorological centres such as ECMWF, NCEP

ALGORITHM / PSEUDO CODE

This section describes our parallel algorithm for rapid meteorological data processing in weather forecasting, based on the PRAM model.

The approach breaks down atmospheric computation tasks so they can be processed simultaneously.

Inputs

- **Meteorological Data Array:** atmospheric measurements (temperature, pressure, humidity, wind, etc.)
- **Parameters for simulation:** grid size, time steps, model constants
- **Number of Processors (P):** available for parallel computation

Steps

1. Initialization:

- Partition meteorological data into P blocks.
- Assign each block to a processor.

2. Parallel Data Loading:

- All processors read assigned data into shared memory concurrently.

3. Parallel Computation:

- For Time Step $t = 1$ to T :
 - Each processor computes updates for its data block based on forecast equations (e.g., Navier-Stokes, temperature, pressure).
 - Shared parameters and neighbouring block data are accessed using PRAM's shared memory model.

4. **Data Assimilation (if needed):**

- At designated intervals, processors update blocks with new observations.
- Synchronize shared memory for assimilated values.

5. **Spectral Transformations:**

- Each processor applies relevant transforms (e.g., FFT) on its block for spectral analysis.

6. **Ensemble Forecasting (optional):**

- Run multiple simulations in parallel, each representing different initial conditions.

7. **Aggregation:**

- Collect results from all processors and aggregate into a unified forecast output.

Output

- Updated forecast data for future time steps, ready for visualization or further analysis.

Example

Suppose we want to predict temperature for 1,000 grid cells over 100-time steps:

- Input: array of temperature and atmospheric measurements for 1,000 cells
- Number of processors: $P = 10$
- Each processor receives 100 cells and processes updates for all time steps simultaneously
- After all steps, processors share and synchronize their results in shared memory for final aggregation

TIME COMPLEXITY

Our Weather Forecasting Algorithm

Aspect	Complexity	Explanation
Input size	n (Grid cells in atmospheric model)	Number of total data points being processed
Time steps	T	Number of forecast intervals processed
Number of processors	P	Processors working in parallel

Sequential Algorithm:

$$O(n \times T)$$

Every grid cell is updated for all time steps one after another.

Parallel PRAM Algorithm:

$$O\left(\frac{n \times T}{P}\right) + O(\log P)$$

Grid cells are divided among P processors. The overhead $O(\log P)$ is for synchronization and communication.

SPACE COMPLEXITY

Aspect	Explanation
Input Data Storage	$O(n)$
Processor State and Memory	$O(P)$ - Each processor maintains local state and temporary variables.
Shared Memory	$O(n)$ - For shared meteorological variables accessed by all processors.

Overall Space Complexity Formula:

$$O(n) + O(P) \approx O(n + P)$$

- The atmospheric data dominates the space requirement.
- Space increases slightly with more processors due to local memory usage.
- PRAM's shared memory model facilitates concurrent access without duplicating data unnecessarily.

CONCLUSION

- Parallel computation using the PRAM model significantly accelerates meteorological data processing for weather forecasting.
- PRAM algorithms effectively decompose complex atmospheric calculations into concurrent tasks, enhancing computational efficiency.
- Time complexity improves approximately by a factor equal to the number of processors, achieving substantial speedup over sequential methods.
- Space complexity remains dominated by data size, with parallelization adding minimal overhead.
- This approach enables scalable, high-resolution weather prediction suitable for real-world forecasting centres.
- PRAM-based parallel algorithms provide a practical foundation for future advancements in numerical weather prediction and environmental modelling.

GitHub Repository Link:

https://github.com/Jagan-Dev-9/DAA_TEAM-10
