**Experimental Results on Dynamic Resource Management for Cloud-native Bulk Synchronous Parallel Applications**

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Results:

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The evaluation of various strategies revealed distinct performance characteristics. The EXXPO strategy, which did not incorporate any dynamic adjustments, resulted in the highest total duration of 65,126.48. The Static Window (3) strategy, using a fixed window size, recorded a total duration of 49,875.18 with 133 checkpoints. While it provided a stable approach, it did not achieve the lowest duration among the strategies tested. The Dynamic Window (2) strategy, which adjusts the window size dynamically, had the lowest total time before checkpointing at 46,981.58. However, its higher number of checkpoints (202) led to a total duration of 50,011.58, making it less efficient overall. The Dynamic MPC (3) strategy, employing model predictive control, achieved a total duration of 49,331.27 with 180 checkpoints. Although it improved upon the Static and Dynamic Window strategies, it still did not perform as well as the most effective strategy. The Reinforcement Learning (3\*10) strategy emerged as the most efficient, with a total duration of 49,158.03 and 135 checkpoints. The Reinforcement Learning strategy is better than the Dynamic MPC strategy by 173.24 seconds. This strategy demonstrated superior performance in optimizing duration and checkpointing intervals compared to the others.

Static Window Strategy:

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Figure 2: Results for Static Window strategy across various window sizes. The Y-axis (left) shows the execution time with and without checkpoint penalty, Y-axis(right) shows the number of checkpoints, and the X-axis shows the window sizes ranging from 1 to 10.

The Static Window Strategy, which updates the configuration every K supersteps (equal to the size of the window), was evaluated with various window sizes to determine its effectiveness. The strategy periodically updates the configuration to optimize performance based on predicted workloads.

Among the tested window sizes, window size 3 proved to be the most effective with the duration of 49875 seconds and 133 checkpoints. It achieved the best balance between the total time taken before checkpointing and the total duration after checkpointing. Larger window sizes generally led to increased total durations, indicating that infrequent updates and larger intervals resulted in less efficient performance. The algorithm optimizes resource configurations for each window by evaluating predicted workloads and making improvements based on performance metrics.

Dynamic Window Strategy:

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Figure 3: Results for Dynamic Window strategy across various window sizes. The Y-axis (left) shows the execution time with and without checkpoint penalty, Y-axis(right) shows the number of checkpoints, and the X-axis shows the window sizes ranging from 1 to 10.

The results depicted in Figure 3, demonstrate how the Dynamic Window strategy handles various window sizes. The Dynamic Window strategy performs best at window size 2, taking lesser duration of 50,011 seconds with a total number of checkpoints as 202 compared to other window sizes when considering the checkpoint cost. And at window size 1, the Dynamic Window strategy gives the highest duration of 52,180 seconds with a total number of checkpoints as 399 when considering the checkpoint cost.

Dynamic MPC Strategy:

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Figure 4: Results for Dynamic MPC strategy across various window sizes. The Y-axis (left) shows the execution time with and without checkpoint penalty, Y-axis(right) shows the number of checkpoints, and the X-axis shows the window sizes ranging from 1 to 10.

The results, depicted in Figure 4, demonstrate how the Dynamic MPC strategy handles various window sizes. The Dynamic MPC strategy performs best at window size 3, taking lesser duration of 49331 seconds with a total number of checkpoints as 133 compared to other window sizes when considering the checkpoint cost. And at window size 1, the Dynamic MPC strategy gives the highest duration of 49796 seconds with a total number of checkpoints as 182 when considering the checkpoint cost.

Reinforcement Learning:

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Figure 5(i)

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Figure 5(ii)

Figure 5(i) and 5 (ii), are the heatmaps for the Reinforcement Learning strategy with and without checkpointing. The Y-axis(left) shows supersteps, Y-axis(right) shows the total execution time and x-axis shows the number of actions considered.

Before considering the checkpointing, we have obtained that Horizon size of 1 and number of actions 9 (i.e., 1\*9) took less duration with 46374 seconds and after considering the checkpoints, the RL model with Horizon size 3 and number of actions 10 (i.e., 3\*10) took the less duration with 49158 seconds with 135 checkpoints.

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Figure 6: Total durations for all strategies under different checkpoint penalty costs. The Y-axis shows the total duration with checkpoint penalty and the X-axis shows the checkpoint penalty cost ranging from 5 to 100.

The results, depicted in Figure 6, demonstrate the impact of the checkpoint penalty cost on the total durations of all strategies. As the checkpoint penalty cost increases, the total duration increases for all strategies, as this cost directly contributes to the total duration. The Reinforcement Leaning strategy has the less total duration until the checkpoint cost reached till 50 and after that Dynamic MPC achieves the best performance by optimizing checkpoint placement based on predictive modeling of future system state.

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Figure 7 illustrates the number of checkpoints for each strategy across various checkpoint penalty costs. The Y-axis represents the number of checkpoints, while the X-axis reflects penalty costs ranging from 5 to 100.

The results show that the Dynamic MPC, and Dynamic Window strategies initially use a high number of checkpoints when the penalty cost is low, but they gradually reduce the number as the penalty cost increases. On the other hand, The static window and the Reinforcement Learning strategy maintains a constant number of checkpoints, deploying 133 and 135 checkpoints respectively, in all cases, regardless of the penalty cost.