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Assignment: HW4

1. Design and Implementation

1.1 Overall Architecture

The program uses one parent process and one child process created by fork(). A unidirectional pipe is used for communication: the parent writes integers to the pipe, while the child reads them.

- Parent process:
    - Creates the pipe.
    - Forks the child process.
    - Closes the read-end of the pipe.
    - Creates 10 producer threads.
    - Waits for all producer threads to finish.
    - Closes the write-end of the pipe.
    - Sends SIGUSR1 to the child to indicate that all numbers have been generated.

- Child process:
    - Installs a SIGUSR1 signal handler.
    - Closes the write-end of the pipe.
    - Waits using pause() until the SIGUSR1 signal is received.
    - Creates 20 consumer threads to read from the pipe.
    - Waits for all consumer threads to finish.
    - Computes the average of the 20 partial sums and prints the result.

1.2 Producer Threads

The parent process creates NUM_PRODUCERS = 10 threads. Each producer thread:

- Generates NUM_PER_PRODUCER = 500 unique random integers in the range [0, 1000]. A local array (used[1001]) is maintained per thread to guarantee uniqueness within that thread.
- Uses rand_r() with a per-thread seed to avoid data races in random generation.
- Before calling write() on the pipe, the thread acquires a mutex (pipe_mutex). This ensures that at most one producer writes to the pipe at a time and prevents interleaving of partial writes.
- After write() completes, the thread releases the mutex.
- Periodically prints progress (every 50 numbers) and a final completion message. A separate mutex (print_mutex) is used to keep console output readable.

This satisfies the requirements of using threads, generating random numbers, and applying synchronization to avoid race conditions and data corruption.

1.3 Consumer Threads

The child process creates NUM_CONSUMERS = 20 threads after receiving SIGUSR1.
Each consumer thread:

- Reads NUM_PER_CONSUMER = 250 integers from the pipe using read().
- Accumulates these values into a local long long sum.
- Stores its result in a global array consumer_sums[tid].
- Prints its own completion message and sum (also protected by print_mutex).

When all consumer threads have completed, the child process:

- Adds up all 20 entries of consumer_sums.
- Computes the average = total / NUM_CONSUMERS.
- Prints the final average to standard output, which is redirected to result.txt.

1.4 Signal Mechanism (Graduate Requirement)

To meet the graduate requirement of signaling:

- The child process installs a signal handler for SIGUSR1:
    - The handler sets a global flag start_reading = 1.
- Before creating any consumer threads, the child calls pause() in a loop:
    - while (!start_reading) pause();
- The parent process sends SIGUSR1 to the child using:
    - kill(child_pid, SIGUSR1);

  but only after:
    - All producer threads have finished.
    - The write-end of the pipe has been closed.

This design guarantees that:

- The child does not start reading from the pipe until all numbers have been generated.
- The signal serves exactly as the notification mechanism required by the assignment.

1.5 Synchronization and Data Integrity

- pipe_mutex: protects write() operations from concurrent producers.
- print_mutex: protects printf() output from multiple threads.
- The pipe itself guarantees ordered delivery of the written integers.