InteractiveBenchmark

May 8, 2024

1 Systems Programming: Project Report

Important: This is a PDF export of the interative benchmark tool ran on my machine (specs below). It is portable and can run it very easily on your machine, just follow the instructions in README.md

1.1 Implemented Features Breakdown

1.1.1 Required Features

- LIFO Scheduler, with stack implemented as a linked list
- Work Stealing Scheduler, with deque implemented as a linked list
- Benchmark results for both schedulers by number of threads, including a comparison between the two

1.1.2 Additional Features

- Interactive benchmarking tool `Interactive Benchmark.ipynb` written in Python (Notebooks) with the ability to run benchmarks for both schedulers with custom parameters and display the results in graphs (one for each scheduler, one for comparison). Running it is easy, just open the notebook, follow the instructions and run the cells. It will automatically adapt to your machine's specs and run the benchmarks.
- Beautiful fractal generation with movement and zoom using the more efficient work stealing scheduler. The fractal is generated using the Mandelbrot set algorithm. The fractal is generated in parallel using a recursive task creation algorithm (Splits width/height until below a threshold). The program is interactive, has the ability to move and zoom smoothly in the fractal. The fractal is displayed using the SDL2 library. It also contains multiple color schemes and a frame time performance benchmark. The fractal generation is implemented in the `fractal` directory. Benchmarks on my machine (specs below) :
  - Using `render_mandelbrot_parallel` function, the frame time is around 0.08s
  - Using `render_mandelbrot` function, the frame time is around 0.3s
  - Parallel version is around 4 times faster than the sequential version
- A synchronizing workstealing scheduler, which never stops running and allows for waiting for the completion of a task. It allows for the fractal (or other graphical programs) to wait for the completion of a task (rendering a frame for example) before starting the next one, using `void wait_for_threads(scheduler *s)` function. It is necessary because the old interface did not allow for that feature, and initializing a scheduler was blocking until the

provided task was done. The synchronizing workstealing scheduler is implemented in the `workstealing_sched_sync.c` file.

- A Makefile with selective compilation options, compiling only the required files for the selected target. Four targets are available: `quicklifo`, `quicksteal`, `stealbench` and `fracsteal`. The `quicklifo` target compiles the LIFO scheduler and the benchmarking tool. The `quicksteal` target compiles the work stealing scheduler and the benchmarking tool. The `stealbench` target compiles the work stealing scheduler for benchmarking. The `fracsteal` target compiles the fractal generation program (uses quick stealing scheduler).
- An exponential backoff algorithm for the work stealing scheduler, which is more efficient than waiting for 1ms every time. The algorithm is implemented in both `work_stealing_sched.c` and `work_stealing_sched_sync.c` files.
- Detailed Work Stealing Scheduler benchmarks with interactive benchmarking tool extension in the bottom of the `Interactive Benchmark.ipynb` notebook. Here is what it does :
  - Benchmarking the number of successful and failed steals by the work stealing scheduler using `steal_success` and `steal_fail` counters. Each thread has it's own counters to not require sync and interfere with performance.
  - Benchmarking the number of tasks done by each thread, to check the efficiency of the scheduler. This is done by calling the logging function `log_task(int thread_id, scheduler *s)` before starting a task.
  - Display the results in a graph, showing the number of successful and failed steals by each thread, and the number of tasks done by each thread.

2 Interactive Benchmark - Schedulers Performance

2.1 Utility functions and benchmark setup

2.1.1 Regex parsing function for the C "time done" output

[3]:
```python
import re

def parse_process_output(output):
    match = re.search(r"\d+\.\d+", output)
    if match:
        number = float(match.group())
    else:
        number = None
    return number
```

2.1.2 Display current specs and initial config

[12]:
```python
import subprocess
import multiprocessing
import matplotlib.pyplot as plt
import numpy as np

cores_count = multiprocessing.cpu_count()
```

```
print("Benchmark done on a 8 core Intel(R) Core(TM) i9-9880H CPU @ 2.30GHz with␣
↪Hyper Threading enabled.")
print(f"Detected {cores_count} cores")

core_values = list(range(1, cores_count + 1))
default_n_size = 10 * 1024 * 1024

multiplier = 10
size = default_n_size * multiplier

print(f"Benchmarking with a size of {multiplier} * 10MB (default quicksort␣
↪size)")
```

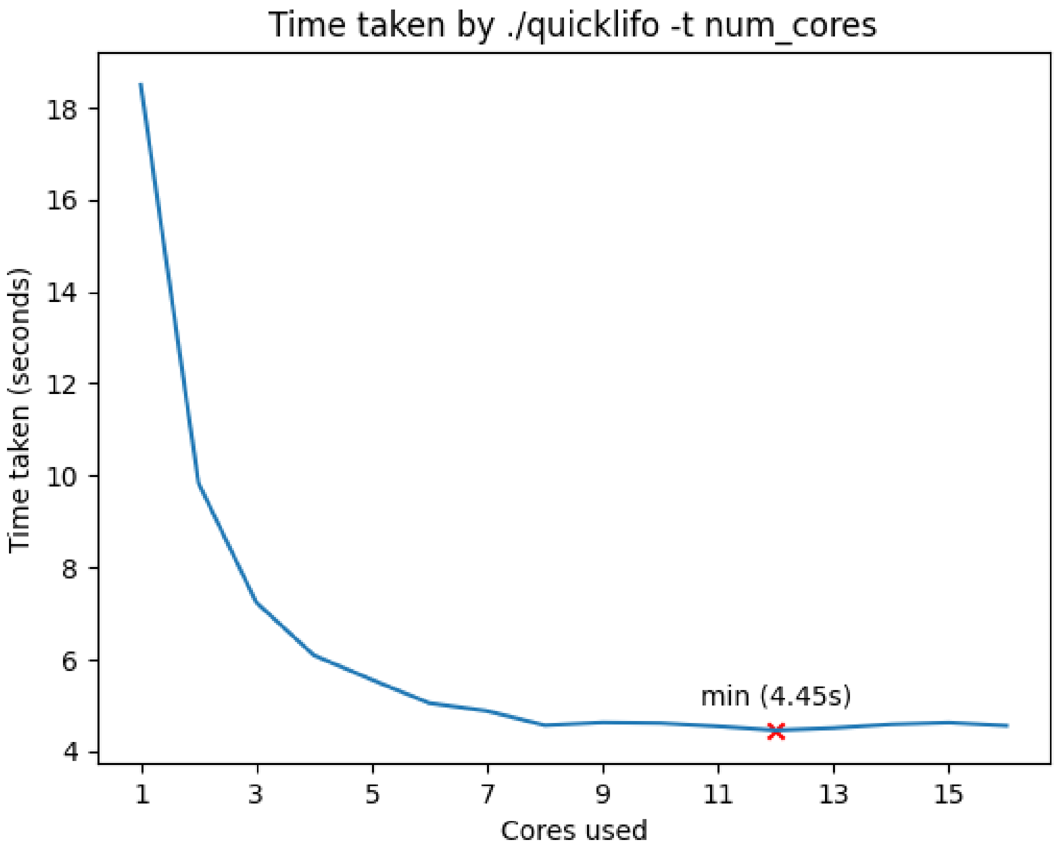
```
Benchmark done on a 8 core Intel(R) Core(TM) i9-9880H CPU @ 2.30GHz with Hyper
Threading enabled.
Detected 16 cores
Benchmarking with a size of 10 * 10MB (default quicksort size)
```

2.2 Benchmarking Quicksort + LIFO scheduler

[5]:
```
PROC_NAME = "quicklifo"

times = []

print(f"Compiling {PROC_NAME}...")
subprocess.run(["make", f"{PROC_NAME}"], check=True, stdout=subprocess.DEVNULL,␣
↪stderr=subprocess.DEVNULL)

print(f"Running benchmarks for ./{PROC_NAME} -t num_cores -n {size}")
for num_cores in core_values:
    proc = subprocess.run([f"./{PROC_NAME}", "-t", str(num_cores), "-n",␣
↪str(size)], check=True, capture_output=True)
    output = proc.stdout.decode().strip()
    time_taken = parse_process_output(output)
    print(f"[{str(num_cores).zfill(2)}] Time taken: {time_taken} seconds")
    times.append(time_taken)

min_time = min(times)
min_index = times.index(min_time)

print(f"Minimum time taken: {min_time} seconds for cores =␣
↪{core_values[min_index]}")

x_ticks = np.arange(min(core_values), max(core_values) + 1, 2)

plt.plot(core_values, times)
plt.scatter(core_values[min_index], min_time, color='red', marker='x')
```

```python
plt.annotate(f"min ({min_time:.2f}s)", (core_values[min_index], min_time),
  ↪textcoords="offset points", xytext=(0, 10), ha='center')
plt.xlabel('Cores used')
plt.ylabel('Time taken (seconds)')
plt.title(f'Time taken by ./{PROC_NAME} -t num_cores')
plt.xticks(x_ticks)
plt.show()

quicklifo_times = times.copy()
```

```
Compiling quicklifo…
Running benchmarks for ./quicklifo -t num_cores -n 104857600
[01] Time taken: 18.502625 seconds
[02] Time taken: 9.830629 seconds
[03] Time taken: 7.231914 seconds
[04] Time taken: 6.079922 seconds
[05] Time taken: 5.549749 seconds
[06] Time taken: 5.039165 seconds
[07] Time taken: 4.867768 seconds
[08] Time taken: 4.557469 seconds
[09] Time taken: 4.617094 seconds
[10] Time taken: 4.6042 seconds
[11] Time taken: 4.533994 seconds
[12] Time taken: 4.447651 seconds
[13] Time taken: 4.49687 seconds
[14] Time taken: 4.577937 seconds
[15] Time taken: 4.614553 seconds
[16] Time taken: 4.548661 seconds
Minimum time taken: 4.447651 seconds for cores = 12
```

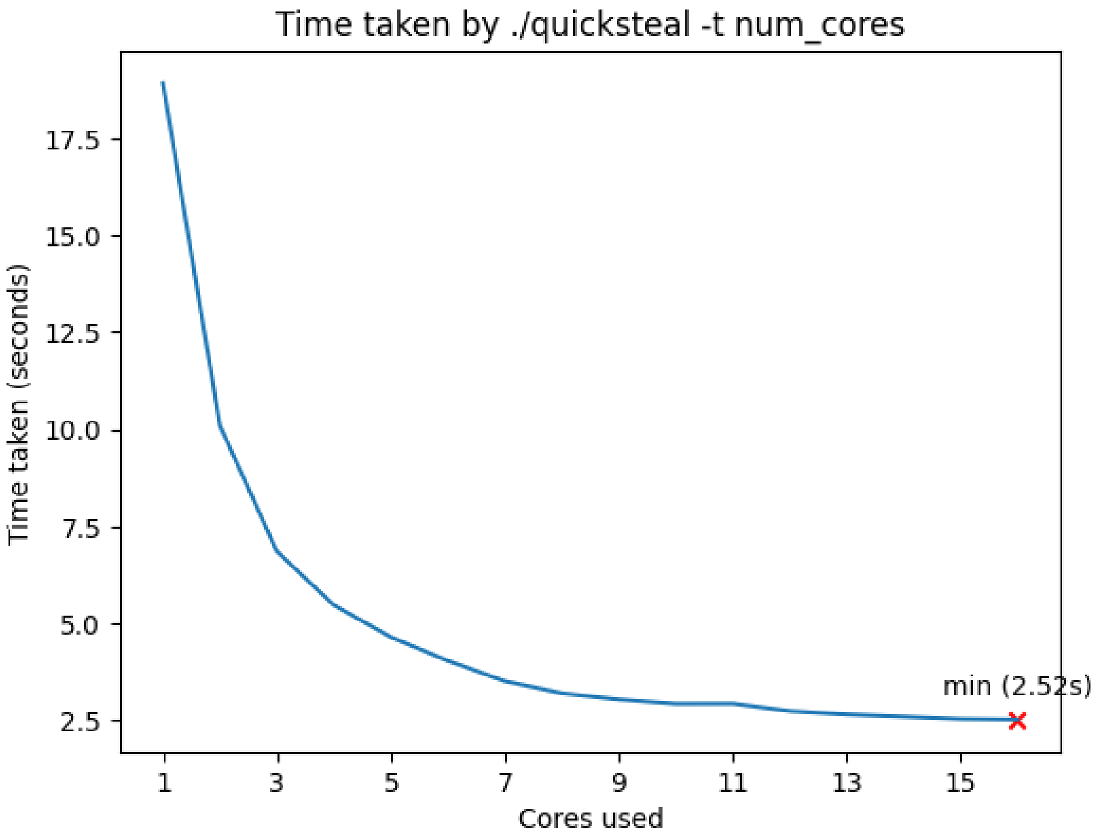


2.3 Benchmarking Quicksort + Work Stealing scheduler

[6]:
```
PROC_NAME = "quicksteal"

times = []

print(f"Compiling {PROC_NAME}...")
subprocess.run(["make", f"{PROC_NAME}"], check=True, stdout=subprocess.DEVNULL,␣
↪stderr=subprocess.DEVNULL)

print(f"Running benchmarks for ./{PROC_NAME} -t num_cores -n {size}")
for num_cores in core_values:
    proc = subprocess.run([f"./{PROC_NAME}", "-t", str(num_cores), "-n",␣
↪str(size)], check=True, capture_output=True)
    output = proc.stdout.decode().strip()
    time_taken = parse_process_output(output)
    print(f"[{str(num_cores).zfill(2)}] Time taken: {time_taken} seconds")
    times.append(time_taken)
```

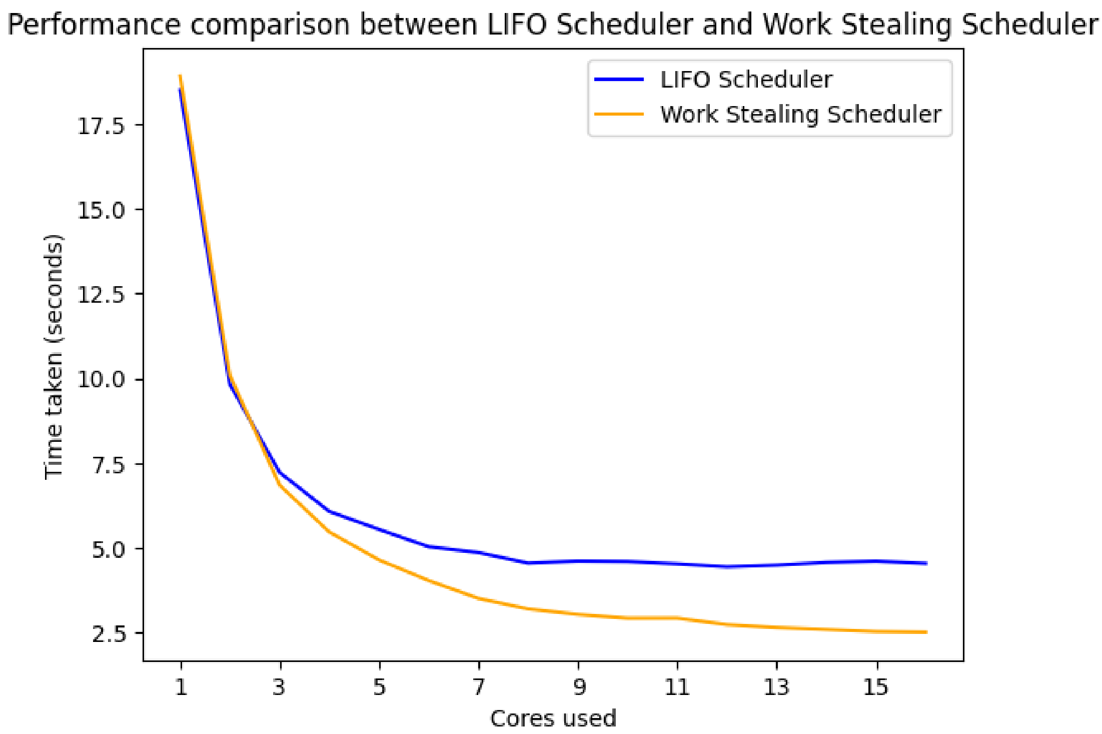
```python
min_time = min(times)
min_index = times.index(min_time)

print(f"Minimum time taken: {min_time} seconds for cores = {core_values[min_index]}")

x_ticks = np.arange(min(core_values), max(core_values) + 1, 2)

plt.plot(core_values, times)
plt.scatter(core_values[min_index], min_time, color='red', marker='x')
plt.annotate(f"min ({min_time:.2f}s)", (core_values[min_index], min_time), textcoords="offset points", xytext=(0, 10), ha='center')
plt.xlabel('Cores used')
plt.ylabel('Time taken (seconds)')
plt.title(f'Time taken by ./{PROC_NAME} -t num_cores')
plt.xticks(x_ticks)
plt.show()

quicksteal_times = times.copy()
```

```
Compiling quicksteal…
Running benchmarks for ./quicksteal -t num_cores -n 104857600
[01] Time taken: 18.917919 seconds
[02] Time taken: 10.099206 seconds
[03] Time taken: 6.857686 seconds
[04] Time taken: 5.474223 seconds
[05] Time taken: 4.651418 seconds
[06] Time taken: 4.042836 seconds
[07] Time taken: 3.516489 seconds
[08] Time taken: 3.206698 seconds
[09] Time taken: 3.044038 seconds
[10] Time taken: 2.932848 seconds
[11] Time taken: 2.934909 seconds
[12] Time taken: 2.745841 seconds
[13] Time taken: 2.658705 seconds
[14] Time taken: 2.601522 seconds
[15] Time taken: 2.540213 seconds
[16] Time taken: 2.523868 seconds
Minimum time taken: 2.523868 seconds for cores = 16
```



2.4 Comparaison Graph

[7]:
```python
x_ticks = np.arange(min(core_values), max(core_values) + 1, 2)

plt.plot(core_values, quicklifo_times, color='blue', label='LIFO Scheduler')
plt.plot(core_values, quicksteal_times, color='orange', label='Work Stealing␣
↪Scheduler')

plt.xlabel('Cores used')
plt.ylabel('Time taken (seconds)')
plt.title('Performance comparison between LIFO Scheduler and Work Stealing␣
↪Scheduler')
plt.xticks(x_ticks)
plt.legend()

plt.show()
```



2.5 Conclusions

- The Work Stealing Scheduler has better average performance than the LIFO Scheduler
- Adding more cores does not increase performance linearly
- More is not always better. There seems to be an optimum < max_cores in both schedulers (overhead > perfomance gains)
- The first few additionnal cores are extremely important for performance. For example, in both cases, using two cores instead of one cuts computing time by half

2.6 Work Stealing Scheduler Specific Benchmarks

2.6.1 Data Parsing

[8]:
```python
def parse_benchmark_data(data):
    lines = data.strip().split('\n')
    success_fail = lines[1].split(',')
    success = int(success_fail[0].split(':')[1].strip())
    fail = int(success_fail[1].split(':')[1].strip())

    thread_tasks = {}
    for line in lines[2:-1]:
        parts = line.split('-')
```

```
        thread_number = int(parts[0].split()[1]) + 1
        task_count = int(parts[1].split()[0].strip())
        thread_tasks[thread_number] = task_count

    return success, fail, thread_tasks
```

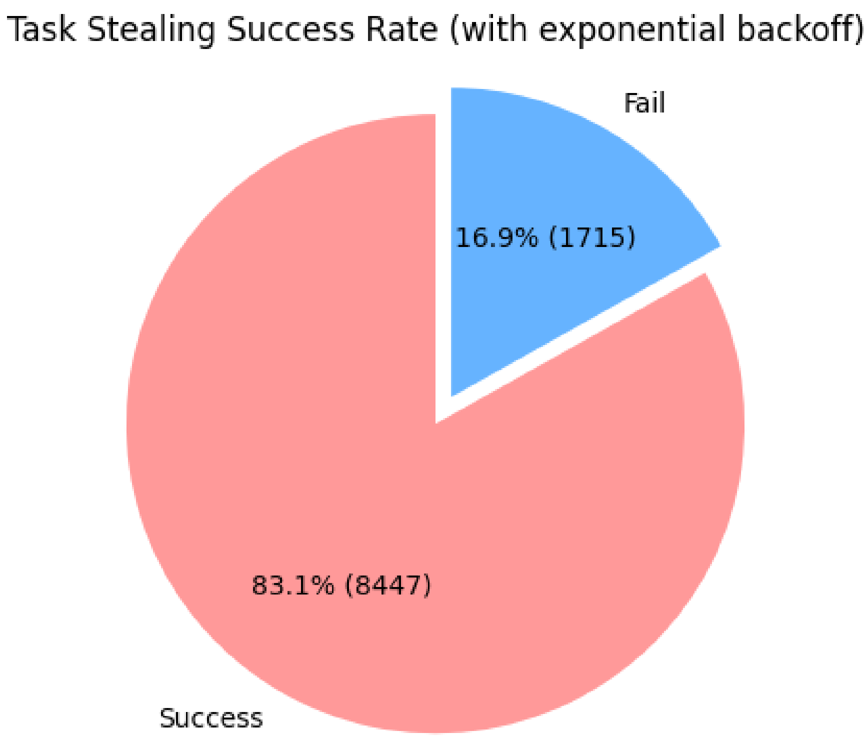
2.6.2 Compile and Run

[9]:
```
PROC_NAME = "stealbench"

print(f"Compiling {PROC_NAME}...")
subprocess.run(["make", f"{PROC_NAME}"], check=True, stdout=subprocess.DEVNULL,
↪stderr=subprocess.DEVNULL)

print(f"Running benchmarks for ./{PROC_NAME} -t 0 (max) -n {size}")
proc = subprocess.run([f"./{PROC_NAME}", "-n", str(size)], check=True,
↪capture_output=True)
output = proc.stdout.decode().strip()
success, fail, thread_tasks = parse_benchmark_data(output)
print(f"Success: {success}, Fail: {fail}")
```

```
Compiling stealbench…
Running benchmarks for ./stealbench -t 0 (max) -n 104857600
Success: 8447, Fail: 1715
```

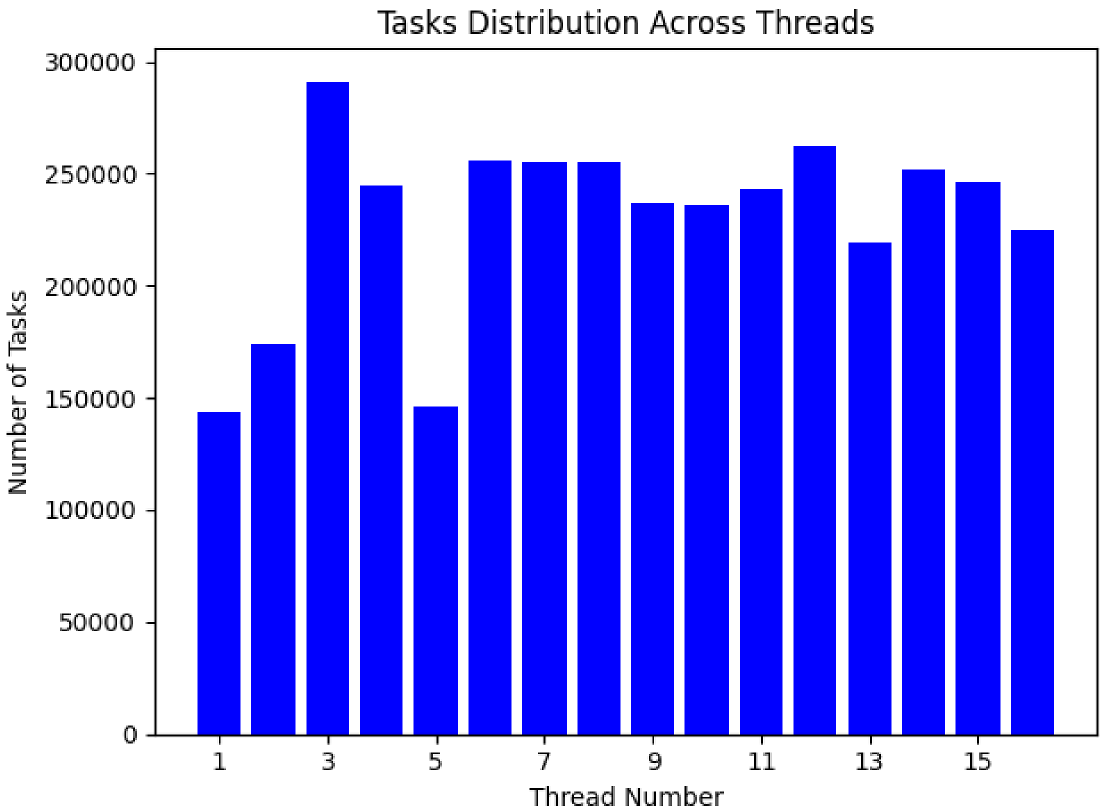
2.6.3 Display Task Stealing Steal Success and Failure Rates

[10]:
```
def value_display(val):
    a  = int(round(val/100.*sum(sizes)))
    return f"{val:.1f}% ({a:d})"


labels = 'Success', 'Fail'
sizes = [success, fail]
colors = ['#ff9999','#66b3ff']
explode = (0.1, 0)

plt.pie(sizes, explode=explode, labels=labels, colors=colors,
↪autopct=value_display, startangle=90)
plt.axis('equal')
plt.title('Task Stealing Success Rate (with exponential backoff)')
plt.show()
```



2.7 Display Task Distribution Across Threads

[11]:
```
threads = list(thread_tasks.keys())
tasks = list(thread_tasks.values())

x_ticks = np.arange(min(core_values), max(core_values) + 1, 2)

plt.bar(threads, tasks, color='blue')
plt.xlabel('Thread Number')
plt.ylabel('Number of Tasks')
plt.xticks(x_ticks)

plt.title('Tasks Distribution Across Threads')
plt.tight_layout()

plt.show()
```


Tasks Distribution Across Threads
Number of Tasks
300000
250000
200000
150000
100000
50000
0
1
3
5
7
9
11
13
15
Thread Number