

5.5 The Santa Claus problem

This problem is from William Stallings's *Operating Systems* [11], but he attributes it to John Trono of St. Michael's College in Vermont.

Stand Claus sleeps in his shop at the North Pole and can only be awakened by either (1) all nine reindeer being back from their vacation in the South Pacific, or (2) some of the elves having difficulty making toys; to allow Santa to get some sleep, the elves can only wake him when three of them have problems. When three elves are having their problems solved, any other elves wishing to visit Santa must wait for those elves to return. If Santa wakes up to find three elves waiting at his shop's door, along with the last reindeer having come back from the tropics, Santa has decided that the elves can wait until after Christmas, because it is more important to get his sleigh ready. (It is assumed that the reindeer do not want to leave the tropics, and therefore they stay there until the last possible moment.) The last reindeer to arrive must get Santa while the others wait in a warming hut before being harnessed to the sleigh.

Here are some addition specifications:

- After the ninth reindeer arrives, Santa must invoke `prepareSleigh`, and then all nine reindeer must invoke `getHitched`.
- After the third elf arrives, Santa must invoke `helpElves`. Concurrently, all three elves should invoke `getHelp`.
- All three elves must invoke `getHelp` before any additional elves enter (increment the elf counter).

Santa should run in a loop so he can help many sets of elves. We can assume that there are exactly 9 reindeer, but there may be any number of elves.

5.5.1 Santa problem hint

Santa problem hint

```
1  elves = 0
2  reindeer = 0
3  santaSem = Semaphore(0)
4  reindeerSem = Semaphore(0)
5  elfTex = Semaphore(1)
6  mutex = Semaphore(1)
```

`elves` and `reindeer` are counters, both protected by `mutex`. Elves and reindeer get `mutex` to modify the counters; Santa gets it to check them.

Santa waits on `santaSem` until either an elf or a reindeer signals him.

The reindeer wait on `reindeerSem` until Santa signals them to enter the paddock and get hitched.

The elves use `elfTex` to prevent additional elves from entering while three elves are being helped.

5.5.2 Santa problem solution

Santa's code is pretty straightforward. Remember that it runs in a loop.

Santa problem solution (Santa)

```
1  santaSem.wait()
2  mutex.wait()
3      if reindeer >= 9:
4          prepareSleigh()
5          reindeerSem.signal(9)
6          reindeer -= 9
7      else if elves == 3:
8          helpElves()
9  mutex.signal()
```

When Santa wakes up, he checks which of the two conditions holds and either deals with the reindeer or the waiting elves. If there are nine reindeer waiting, Santa invokes `prepareSleigh`, then signals `reindeerSem` nine times, allowing the reindeer to invoke `getHitched`. If there are elves waiting, Santa just invokes `helpElves`. There is no need for the elves to wait for Santa; once they signal `santaSem`, they can invoke `getHelp` immediately.

Santa doesn't have to decrement the `elves` counter because the elves do it on their way out.

Here is the code for reindeer:

Santa problem solution (reindeer)

```
1  mutex.wait()
2      reindeer += 1
3      if reindeer == 9:
4          santaSem.signal()
5  mutex.signal()
6
7  reindeerSem.wait()
8  getHitched()
```

The ninth reindeer signals Santa and then joins the other reindeer waiting on `reindeerSem`. When Santa signals, the reindeer all execute `getHitched`.

The elf code is similar, except that when the third elf arrives it has to bar subsequent arrivals until the first three have executed `getHelp`.

Santa problem solution (elves)

```
1 elfTex.wait()
2 mutex.wait()
3     elves += 1
4     if elves == 3:
5         santaSem.signal()
6     else
7         elfTex.signal()
8 mutex.signal()
9
10 getHelp()
11
12 mutex.wait()
13     elves -= 1
14     if elves == 0:
15         elfTex.signal()
16 mutex.signal()
```

The first two elves release `elfTex` at the same time they release the `mutex`, but the last elf holds `elfTex`, barring other elves from entering until all three elves have invoked `getHelp`.

The last elf to leave releases `elfTex`, allowing the next batch of elves to enter.