

6.1 Guessing+Induction

First we need to get rid of the \mathcal{O} -notation in our recurrence:

$$T(n) \leq \begin{cases} 2T(\lceil \frac{n}{2} \rceil) + cn & n \geq 2 \\ 0 & \text{otherwise} \end{cases}$$

Assume that instead we had

$$T(n) \leq \begin{cases} 2T(\frac{n}{2}) + cn & n \geq 2 \\ 0 & \text{otherwise} \end{cases}$$

One way of solving such a recurrence is to **guess** a solution, and check that it is correct by plugging it in.

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Suppose we guess $T(n) \leq dn \log n$ for a constant d . Then

$$\begin{aligned}T(n) &\leq 2T\left(\frac{n}{2}\right) + cn \\&\leq 2\left(d\frac{n}{2}\log\frac{n}{2}\right) + cn \\&= dn(\log n - 1) + cn \\&= dn \log n + (c - d)n \\&\leq dn \log n\end{aligned}$$

if we choose $d \geq c$.

Formally one would make an induction proof, where the above is the induction step. The base case is usually trivial.

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$$T(n) \leq \begin{cases} 2T\left(\frac{n}{2}\right) + cn & n \geq 16 \\ b & \text{otw.} \end{cases}$$

Guess: $T(n) \leq dn \log n$.

Proof. (by induction)

- ▶ **base case** ($2 \leq n < 16$): **true** if we choose $d \geq b$.
- ▶ **induction step** $2 \dots n-1 \rightarrow n$:

Suppose statem. is true for $n' \in \{2, \dots, n-1\}$, and $n \geq 16$.

We prove it for n :

$$\begin{aligned} T(n) &\leq 2T\left(\frac{n}{2}\right) + cn \\ &\leq 2\left(d\frac{n}{2} \log \frac{n}{2}\right) + cn \\ &= dn(\log n - 1) + cn \\ &= dn \log n + (c - d)n \\ &\leq dn \log n \end{aligned}$$

- Note that this proves the statement for $n \in \mathbb{N}_{\geq 2}$, as the statement is wrong for $n = 1$.
- The base case is usually omitted, as it is the same for different recurrences.

Hence, statement is **true** if we choose $d \geq c$.

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Why did we change the recurrence by getting rid of the ceiling?

If we do not do this we instead consider the following recurrence:

$$T(n) \leq \begin{cases} 2T(\lceil \frac{n}{2} \rceil) + cn & n \geq 16 \\ b & \text{otherwise} \end{cases}$$

Note that we can do this as for constant-sized inputs the running time is always some constant (b in the above case).

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We also make a guess of $T(n) \leq dn \log n$ and get

$$\begin{aligned}T(n) &\leq 2T\left(\left\lceil \frac{n}{2} \right\rceil\right) + cn \\&\leq 2\left(d\left\lceil \frac{n}{2} \right\rceil \log \left\lceil \frac{n}{2} \right\rceil\right) + cn \\&\leq 2(d(n/2 + 1) \log(n/2 + 1)) + cn \\&\leq dn \log\left(\frac{9}{16}n\right) + 2d \log n + cn \\&= dn \log n + (\log 9 - 4)dn + 2d \log n + cn \\&\leq dn \log n + (\log 9 - 3.5)dn + cn \\&\leq dn \log n - 0.33dn + cn \\&\leq dn \log n\end{aligned}$$

$$\left\lceil \frac{n}{2} \right\rceil \leq \frac{n}{2} + 1$$

$$\frac{n}{2} + 1 \leq \frac{9}{16}n$$

$$\log \frac{9}{16}n = \log n + (\log 9 - 4)$$

$$\log n \leq \frac{n}{4}$$

for a suitable choice of d .