VII

Technical Questions

Technical questions form the basis for how many of the top tech companies interview. Many candidates are intimidated by the difficulty of these questions, but there are logical ways to approach them.

How to Prepare

Many candidates just read through problems and solutions. That's like trying to learn calculus by reading a problem and its answer. You need to practice solving problems. Memorizing solutions won't help you much.

For each problem in this book (and any other problem you might encounter), do the following:

1. *Try to solve the problem on your own.* Hints are provided at the back of this book, but push yourself to develop a solution with as little help as possible. Many questions are designed to be tough—that's okay! When you're solving a problem, make sure to think about the space and time efficiency.
2. *Write the code on paper.* Coding on a computer offers luxuries such as syntax highlighting, code completion, and quick debugging. Coding on paper does not. Get used to this—and to how slow it is to write and edit code—by coding on paper.
3. *Test your code—on paper.* This means testing the general cases, base cases, error cases, and so on. You'll need to do this during your interview, so it's best to practice this in advance.
4. *Type your paper code as-is into a computer.* You will probably make a bunch of mistakes. Start a list of all the errors you make so that you can keep these in mind during the actual interview.

In addition, try to do as many mock interviews as possible. You and a friend can take turns giving each other mock interviews. Though your friend may not be an expert interviewer, he or she may still be able to walk you through a coding or algorithm problem. You'll also learn a lot by experiencing what it's like to be an interviewer.

What You Need To Know

The sorts of data structure and algorithm questions that many companies focus on are not knowledge tests. However, they do assume a baseline of knowledge.

Core Data Structures, Algorithms, and Concepts

Most interviewers won't ask about specific algorithms for binary tree balancing or other complex algorithms. Frankly, being several years out of school, they probably don't remember these algorithms either.

You're usually only expected to know the basics. Here's a list of the absolute, must-have knowledge:

Data Structures	Algorithms	Concepts
Linked Lists	Breadth-First Search	Bit Manipulation
Trees, Tries, & Graphs	Depth-First Search	Memory (Stack vs. Heap)
Stacks & Queues	Binary Search	Recursion
Heaps	Merge Sort	Dynamic Programming
Vectors / ArrayLists	Quick Sort	Big O Time & Space
Hash Tables		

For each of these topics, make sure you understand how to use and implement them and, where applicable, the space and time complexity.

Practicing implementing the data structures and algorithm (on paper, and then on a computer) is also a great exercise. It will help you learn how the internals of the data structures work, which is important for many interviews.

> Did you miss that paragraph above? It's important. If you don't feel very, very comfortable with each of the data structures and algorithms listed, practice implementing them from scratch.

In particular, hash tables are an extremely important topic. Make sure you are very comfortable with this data structure.

Powers of 2 Table

The table below is useful for many questions involving scalability or any sort of memory limitation. Memorizing this table isn't strictly required, but it can be useful. You should at least be comfortable deriving it.

Power of 2	Exact Value (X)	Approx. Value	X Bytes into MB, GB, etc.
7	128		
8	256		
10	1024	1 thousand	1 KB
16	65,536		64 KB
20	1,048,576	1 million	1 MB
30	1,073,741,824	1 billion	1 GB
32	4,294,967,296		4 GB
40	1,099,511,627,776	1 trillion	1 TB

For example, you could use this table to quickly compute that a bit vector mapping every 32-bit integer to a boolean value could fit in memory on a typical machine. There are 2^{32} such integers. Because each integer takes one bit in this bit vector, we need 2^{32} bits (or 2^{29} bytes) to store this mapping. That's about half a gigabyte of memory, which can be easily held in memory on a typical machine.

If you are doing a phone screen with a web-based company, it may be useful to have this table in front of you.

Walking Through a Problem

The below map/flowchart walks you through how to solve a problem. Use this in your practice. You can download this handout and more at CrackingTheCodingInterview.com.

A Problem-Solving Flowchart

1 Listen

Pay very close attention to any information in the problem description. You probably need it all for an optimal algorithm.

2 Example

Most examples are too small or are special cases. **Debug your example.** Is there any way it's a special case? Is it big enough?

3 Brute Force

Get a brute-force solution as soon as possible. Don't worry about developing an efficient algorithm yet. State a naive algorithm and its runtime, then optimize from there. Don't code yet though!

BUD Optimization

Bottlenecks

Unnecessary Work

Duplicated Work

4 Optimize

Walk through your brute force with **BUD optimization** or try some of these ideas:

- Look for any unused info. You usually need all the information in a problem.
- Solve it manually on an example, then reverse engineer your thought process. How did you solve it?
- Solve it "incorrectly" and then think about why the algorithm fails. Can you fix those issues?
- Make a time vs. space tradeoff. Hash tables are especially useful!

5 Walk Through

Now that you have an optimal solution, **walk through your approach in detail.** Make sure you understand each detail before you start coding.

6 Implement

Your goal is to **write beautiful code.** Modularize your code from the beginning and refactor to clean up anything that isn't beautiful.

Keep talking! Your interviewer wants to hear how you approach the problem.

7 Test

Test in this order:

1. Conceptual test. Walk through your code like you would for a detailed code review.
2. Unusual or non-standard code.
3. Hot spots, like arithmetic and null nodes.
4. Small test cases. It's much faster than a big test case and just as effective.
5. Special cases and edge cases.

And when you find bugs, **fix them carefully!**

We'll go through this flowchart in more detail.

What to Expect

Interviews are supposed to be difficult. If you don't get every—or any—answer immediately, that's okay! That's the normal experience, and it's not bad.

Listen for guidance from the interviewer. The interviewer might take a more active or less active role in your problem solving. The level of interviewer participation depends on your performance, the difficulty of the question, what the interviewer is looking for, and the interviewer's own personality.

When you're given a problem (or when you're practicing), work your way through it using the approach below.

1. Listen Carefully

You've likely heard this advice before, but I'm saying something a bit more than the standard "make sure you hear the problem correctly" advice.

Yes, you do want to listen to the problem and make sure you heard it correctly. You do want to ask questions about anything you're unsure about.

But I'm saying something more than that.

Listen carefully to the problem, and be sure that you've mentally recorded any *unique* information in the problem.

For example, suppose a question starts with one of the following lines. It's reasonable to assume that the information is there for a reason.

- "Given two arrays that are sorted, find ..."

  You probably need to know that the data is sorted. The optimal algorithm for the sorted situation is probably different than the optimal algorithm for the unsorted situation.

- "Design an algorithm to be run repeatedly on a server that ..."

  The server/to-be-run-repeatedly situation is different from the run-once situation. Perhaps this means that you cache data? Or perhaps it justifies some reasonable precomputation on the initial dataset?

It's unlikely (although not impossible) that your interviewer would give you this information if it didn't affect the algorithm.

Many candidates will hear the problem correctly. But ten minutes into developing an algorithm, some of the key details of the problem have been forgotten. Now they are in a situation where they actually can't solve the problem optimally.

Your first algorithm doesn't need to use the information. But if you find yourself stuck, or you're still working to develop something more optimal, ask yourself if you've used all the information in the problem.

You might even find it useful to write the pertinent information on the whiteboard.

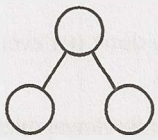
2. Draw an Example

An example can dramatically improve your ability to solve an interview question, and yet so many candidates just try to solve the question in their heads.

When you hear a question, get out of your chair, go to the whiteboard, and draw an example.

There's an art to drawing an example though. You want a good example.

Very typically, a candidate might draw something like this for an example of a binary search tree:



This is a bad example for several reasons. First, it's too small. You will have trouble finding a pattern in such a small example. Second, it's not specific. A binary search tree has values. What if the numbers tell you something about how to approach the problem? Third, it's actually a special case. It's not just a balanced tree, but it's also a beautiful, perfect tree where every node other than the leaves has two children. Special cases can be very deceiving.

Instead, you want to create an example that is:

- Specific. It should use real numbers or strings (if applicable to the problem).
- Sufficiently large. Most examples are too small, by about 50%.
- Not a special case. Be careful. It's very easy to inadvertently draw a special case. If there's any way your example is a special case (even if you think it probably won't be a big deal), you should fix it.

Try to make the best example you can. If it later turns out your example isn't quite right, you can and should fix it.

3. State a Brute Force

Once you have an example done (actually, you can switch the order of steps 2 and 3 in some problems), state a brute force. It's okay and expected that your initial algorithm won't be very optimal.

Some candidates don't state the brute force because they think it's both obvious and terrible. But here's the thing: Even if it's obvious for you, it's not necessarily obvious for all candidates. You don't want your interviewer to think that you're struggling to see even the easy solution.

It's okay that this initial solution is terrible. Explain what the space and time complexity is, and then dive into improvements.

Despite being possibly slow, a brute force algorithm is valuable to discuss. It's a starting point for optimizations, and it helps you wrap your head around the problem.

4. Optimize

Once you have a brute force algorithm, you should work on optimizing it. A few techniques that work well are:

1. Look for any unused information. Did your interviewer tell you that the array was sorted? How can you leverage that information?
2. Use a fresh example. Sometimes, just seeing a different example will unclog your mind or help you see a pattern in the problem.
3. Solve it "incorrectly." Just like having an inefficient solution can help you find an efficient solution, having an incorrect solution might help you find a correct solution. For example, if you're asked to generate a

random value from a set such that all values are equally likely, an incorrect solution might be one that returns a semi-random value: Any value could be returned, but some are more likely than others. You can then think about why that solution isn't perfectly random. Can you rebalance the probabilities?

4. Make time vs. space tradeoff. Sometimes storing extra state about the problem can help you optimize the runtime.
5. Precompute information. Is there a way that you can reorganize the data (sorting, etc.) or compute some values upfront that will help save time in the long run?
6. Use a hash table. Hash tables are widely used in interview questions and should be at the top of your mind.
7. Think about the best conceivable runtime (discussed on page 72).

Walk through the brute force with these ideas in mind and look for BUD (page 67).

5. Walk Through

After you've nailed down an optimal algorithm, don't just dive into coding. Take a moment to solidify your understanding of the algorithm.

Whiteboard coding is slow—very slow. So is testing your code and fixing it. As a result, you need to make sure that you get it as close to "perfect" in the beginning as possible.

Walk through your algorithm and get a feel for the structure of the code. Know what the variables are and when they change.

> What about pseudocode? You can write pseudocode if you'd like. Be careful about what you write. Basic steps ("(1) Search array. (2) Find biggest. (3) Insert in heap.") or brief logic ("if p < q, move p. else move q") can be valuable. But when your pseudocode starts having for loops that are written in plain English, then you're essentially just writing sloppy code. It'd probably be faster to just write the code.

If you don't understand exactly what you're about to write, you'll struggle to code it. It will take you longer to finish the code, and you're more likely to make major errors.

6. Implement

Now that you have an optimal algorithm and you know exactly what you're going to write, go ahead and implement it.

Start coding in the far top left corner of the whiteboard (you'll need the space). Avoid "line creep" (where each line of code is written an awkward slant). It makes your code look messy and can be very confusing when working in a whitespace-sensitive language, like Python.

Remember that you only have a short amount of code to demonstrate that you're a great developer. Everything counts. Write beautiful code.

Beautiful code means:

- Modularized code. This shows good coding style. It also makes things easier for you. If your algorithm uses a matrix initialized to `{{1, 2, 3}, {4, 5, 6}, ...}`, don't waste your time writing this initialization code. Just pretend you have a function `initIncrementalMatrix(int size)`. Fill in the details later if you need to.

- Error checks. Some interviewers care a lot about this, while others don't. A good compromise here is to add a `todo` and then just explain out loud what you'd like to test.
- Use other classes/structs where appropriate. If you need to return a list of start and end points from a function, you could do this as a two-dimensional array. It's better though to do this as a list of `StartEndPair` (or possibly `Range`) objects. You don't necessarily have to fill in the details for the class. Just pretend it exists and deal with the details later if you have time.
- Good variable names. Code that uses single-letter variables everywhere is difficult to read. That's not to say that there's anything wrong with using `i` and `j`, where appropriate (such as in a basic for-loop iterating through an array). However, be careful about where you do this. If you write something like `int i = startOfChild(array)`, there might be a better name for this variable, such as `startChild`.

  Long variable names can also be slow to write though. A good compromise that most interviewers will be okay with is to abbreviate it after the first usage. You can use `startChild` the first time, and then explain to your interviewer that you will abbreviate this as `sc` after this.

The specifics of what makes good code vary between interviewers and candidates, and the problem itself. Focus on writing beautiful code, whatever that means to you.

If you see something you can refactor later on, then explain this to your interviewer and decide whether or not it's worth the time to do so. Usually it is, but not always.

If you get confused (which is common), go back to your example and walk through it again.

7. Test

You wouldn't check in code in the real world without testing it, and you shouldn't "submit" code in an interview without testing it either.

There are smart and not-so-smart ways to test your code though.

What many candidates do is take their earlier example and test it against their code. That might discover bugs, but it'll take a really long time to do so. Hand testing is very slow. If you really did use a nice, big example to develop your algorithm, then it'll take you a very long time to find that little off-by-one error at the end of your code.

Instead, try this approach:

1. Start with a "conceptual" test. A conceptual test means just reading and analyzing what each line of code does. Think about it like you're explaining the lines of code for a code reviewer. Does the code do what you think it should do?
2. Weird looking code. Double check that line of code that says `x = length - 2`. Investigate that for loop that starts at `i = 1`. While you undoubtedly did this for a reason, it's really easy to get it just slightly wrong.
3. Hot spots. You've coded long enough to know what things are likely to cause problems. Base cases in recursive code. Integer division. Null nodes in binary trees. The start and end of iteration through a linked list. Double check that stuff.
4. Small test cases. This is the first time we use an actual, specific test case to test the code. Don't use that nice, big 8-element array from the algorithm part. Instead, use a 3 or 4 element array. It'll likely discover the same bugs, but it will be much faster to do so.
5. Special cases. Test your code against null or single element values, the extreme cases, and other special cases.

When you find bugs (and you probably will), you should of course fix them. But don't just make the first correction you think of. Instead, carefully analyze why the bug occurred and ensure that your fix is the best one.

▸ Optimize & Solve Technique #1: Look for BUD

This is perhaps the most useful approach I've found for optimizing problems. "BUD" is a silly acronym for:

- **B**ottlenecks
- **U**nnecessary work
- **D**uplicated work

These are three of the most common things that an algorithm can "waste" time doing. You can walk through your brute force looking for these things. When you find one of them, you can then focus on getting rid of it.

If it's still not optimal, you can repeat this approach on your current best algorithm.

Bottlenecks

A bottleneck is a part of your algorithm that slows down the overall runtime. There are two common ways this occurs:

- You have one-time work that slows down your algorithm. For example, suppose you have a two-step algorithm where you first sort the array and then you find elements with a particular property. The first step is `O(N log N)` and the second step is `O(N)`. Perhaps you could reduce the second step to `O(log N)` or `O(1)`, but would it matter? Not too much. It's certainly not a priority, as the `O(N log N)` is the bottleneck. Until you optimize the first step, your overall algorithm will be `O(N log N)`.
- You have a chunk of work that's done repeatedly, like searching. Perhaps you can reduce that from `O(N)` to `O(log N)` or even `O(1)`. That will greatly speed up your overall runtime.

Optimizing a bottleneck can make a big difference in your overall runtime.

> Example: Given an array of distinct integer values, count the number of pairs of integers that have difference k. For example, given the array `{1, 7, 5, 9, 2, 12, 3}` and the difference `k = 2`, there are four pairs with difference 2: `(1, 3), (3, 5), (5, 7), (7, 9)`.

A brute force algorithm is to go through the array, starting from the first element, and then search through the remaining elements (which will form the other side of the pair). For each pair, compute the difference. If the difference equals k, increment a counter of the difference.

The bottleneck here is the repeated search for the "other side" of the pair. It's therefore the main thing to focus on optimizing.

How can we more quickly find the right "other side"? Well, we actually know the other side of `(x, ?)`. It's `x + k` or `x - k`. If we sorted the array, we could find the other side for each of the `N` elements in `O(log N)` time by doing a binary search.

We now have a two-step algorithm, where both steps take `O(N log N)` time. Now, sorting is the new bottleneck. Optimizing the second step won't help because the first step is slowing us down anyway.

We just have to get rid of the first step entirely and operate on an unsorted array. How can we find things quickly in an unsorted array? With a hash table.

Throw everything in the array into the hash table. Then, to look up if x + k or x - k exist in the array, we just look it up in the hash table. We can do this in O(N) time.

Unnecessary Work

Example: Print all positive integer solutions to the equation $a^3 + b^3 = c^3 + d^3$ where a, b, c, and d are integers between 1 and 1000.

A brute force solution will just have four nested for loops. Something like:

```
1  n = 1000
2  for a from 1 to n
3    for b from 1 to n
4      for c from 1 to n
5        for d from 1 to n
6          if a³ + b³ == c³ + d³
7            print a, b, c, d
```

This algorithm iterates through all possible values of a, b, c, and d and checks if that combination happens to work.

It's unnecessary to continue checking for other possible values of d. Only one could work. We should at least break after we find a valid solution.

```
1  n = 1000
2  for a from 1 to n
3    for b from 1 to n
4      for c from 1 to n
5        for d from 1 to n
6          if a³ + b³ == c³ + d³
7            print a, b, c, d
8            break // break out of d's loop
```

This won't make a meaningful change to the runtime—our algorithm is still $O(N^4)$—but it's still a good, quick fix to make.

Is there anything else that is unnecessary? Yes. If there's only one valid d value for each (a, b, c), then we can just compute it. This is just simple math: $d = \sqrt[3]{a^3 + b^3 - c^3}$.

```
1  n = 1000
2  for a from 1 to n
3    for b from 1 to n
4      for c from 1 to n
5        d = pow(a³ + b³ - c³, 1/3) // Will round to int
6        if a³ + b³ == c³ + d³ // Validate that the value works
7          print a, b, c, d
```

The `if` statement on line 6 is important. Line 5 will always find a value for d, but we need to check that it's the right integer value.

This will reduce our runtime from $O(N^4)$ to $O(N^3)$.

Duplicated Work

Using the same problem and brute force algorithm as above, let's look for duplicated work this time.

The algorithm operates by essentially iterating through all `(a, b)` pairs and then searching all `(c, d)` pairs to find if there are any matches to that `(a, b)` pair.

Why do we keep on computing all (c, d) pairs for each (a, b) pair? We should just create the list of (c, d) pairs once. Then, when we have an (a, b) pair, find the matches within the (c, d) list. We can quickly locate the matches by inserting each (c, d) pair into a hash table that maps from the sum to the pair (or, rather, the list of pairs that have that sum).

```
1   n = 1000
2   for c from 1 to n
3     for d from 1 to n
4       result = c³ + d³
5       append (c, d) to list at value map[result]
6   for a from 1 to n
7     for b from 1 to n
8       result = a³ + b³
9       list = map.get(result)
10      for each pair in list
11        print a, b, pair
```

Actually, once we have the map of all the (c, d) pairs, we can just use that directly. We don't need to generate the (a, b) pairs. Each (a, b) will already be in the map.

```
1   n = 1000
2   for c from 1 to n
3     for d from 1 to n
4       result = c³ + d³
5       append (c, d) to list at value map[result]
6
7   for each result, list in map
8     for each pair1 in list
9       for each pair2 in list
10        print pair1, pair2
```

This will take our runtime to $O(N^2)$.

▸ Optimize & Solve Technique #2: DIY (Do It Yourself)

The first time you heard about how to find an element in a sorted array (before being taught binary search), you probably didn't jump to, "Ah ha! We'll compare the target element to the midpoint and then recurse on the appropriate half."

And yet, you could give someone who has no knowledge of computer science an alphabetized pile of student papers and they'll likely implement something like binary search to locate a student's paper. They'll probably say, "Gosh, Peter Smith? He'll be somewhere in the bottom of the stack." They'll pick a random paper in the middle(ish), compare the name to "Peter Smith", and then continue this process on the remainder of the papers. Although they have no knowledge of binary search, they intuitively "get it."

Our brains are funny like this. Throw the phrase "Design an algorithm" in there and people often get all jumbled up. But give people an actual example—whether just of the data (e.g., an array) or of the real-life parallel (e.g., a pile of papers)—and their intuition gives them a very nice algorithm.

I've seen this come up countless times with candidates. Their computer algorithm is extraordinarily slow, but when asked to solve the same problem manually, they immediately do something quite fast. (And it's not too surprisingly, in some sense. Things that are slow for a computer are often slow by hand. Why would you put yourself through extra work?)

Therefore, when you get a question, try just working it through intuitively on a real example. Often a bigger example will be easier.