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Data Stream Algorithms

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Agenda

- What is a Data Stream?
- Why are Data Streams difficult to process?
- Common problems and generic solutions
- Heavy Hitters problem
- Takeaways

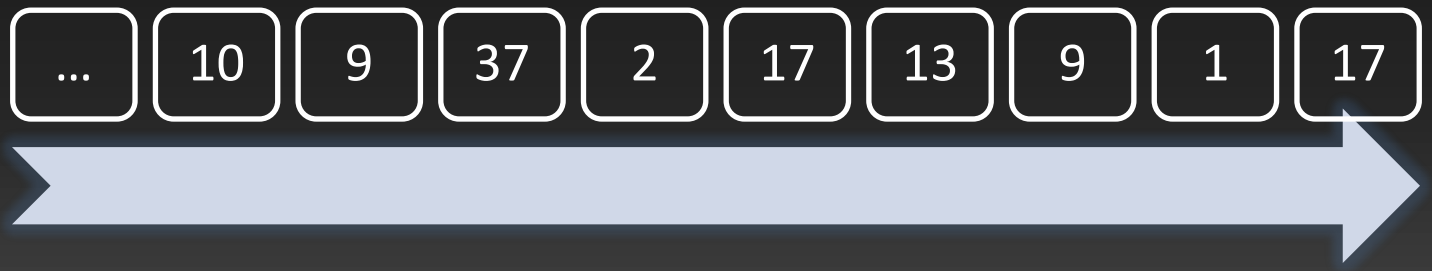
What is a Data Stream?

- Large Data Set which is hard to:
  - Process (by classic algorithms)
  - Transfer
  - Store (in a single location)

- Examples:
  - Sensor data from Curiosity, LHC
  - Traffic on a backbone router
  - Traffic to a popular website (Google, Amazon, Facebook)
  - DDoS traffic to a website

Difficult to process

- Unbounded number of elements

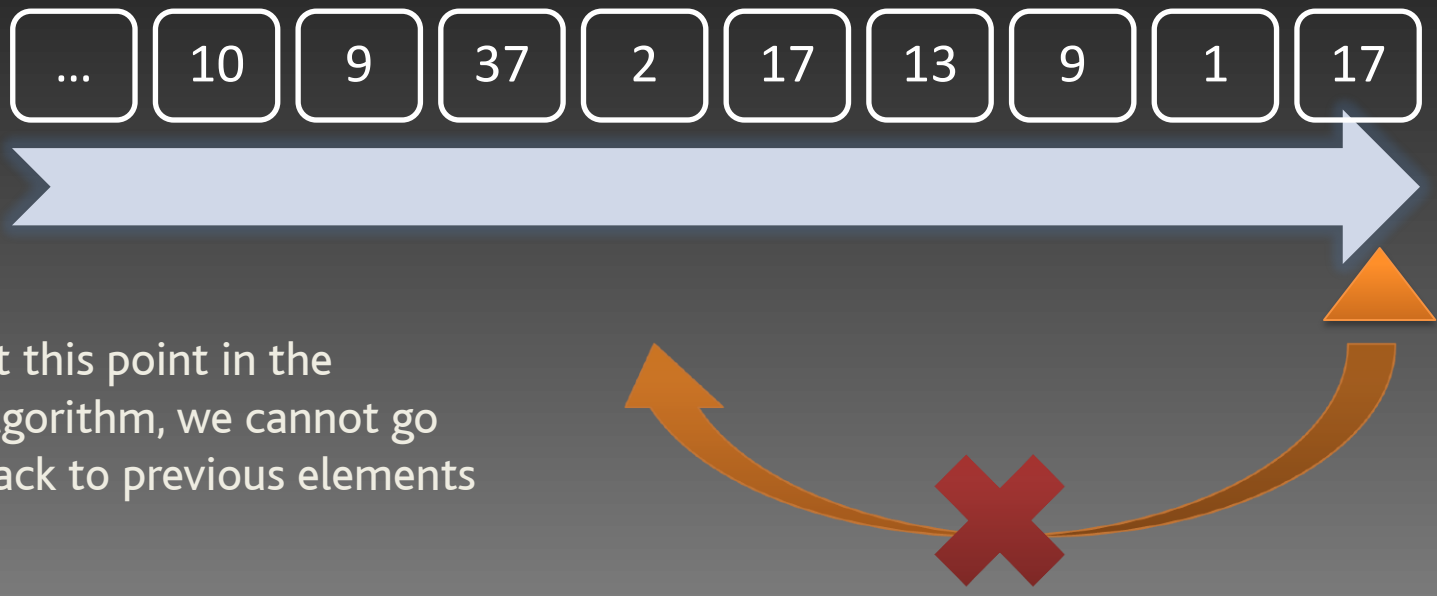


Element	1	2	9	10	13	17	...
Count	1	1	2	1	1	2	...

...but we want finite (pre-determined) space, depending on the problem

Difficult to process

- Short processing time for each element in the stream
- No random data access



Common problems …

- Summary of data
  - Sampling
  - Statistics: average, median, percentile, histogram
  - Distinct elements
  - Most frequent elements, top k elements
- Filtering
- Data stream mining
- Data stream clustering
- Pattern matching

… and generic solutions

- Almost all algorithms are approximate
- We assume worst case input
- Use random inside the algorithm (not in data)

As a result:

- Non-intuitive (“hard”) algorithms
- Error analysis is hard
- Both space and time complexity are important

… and generic solutions

- "Sketching" a general technique
  - Try to build a small data-structure to represent the data you want to obtain from the stream
  - The smaller the data structure, the less accurate the results
  - Usually use hashing when accessing the data structure

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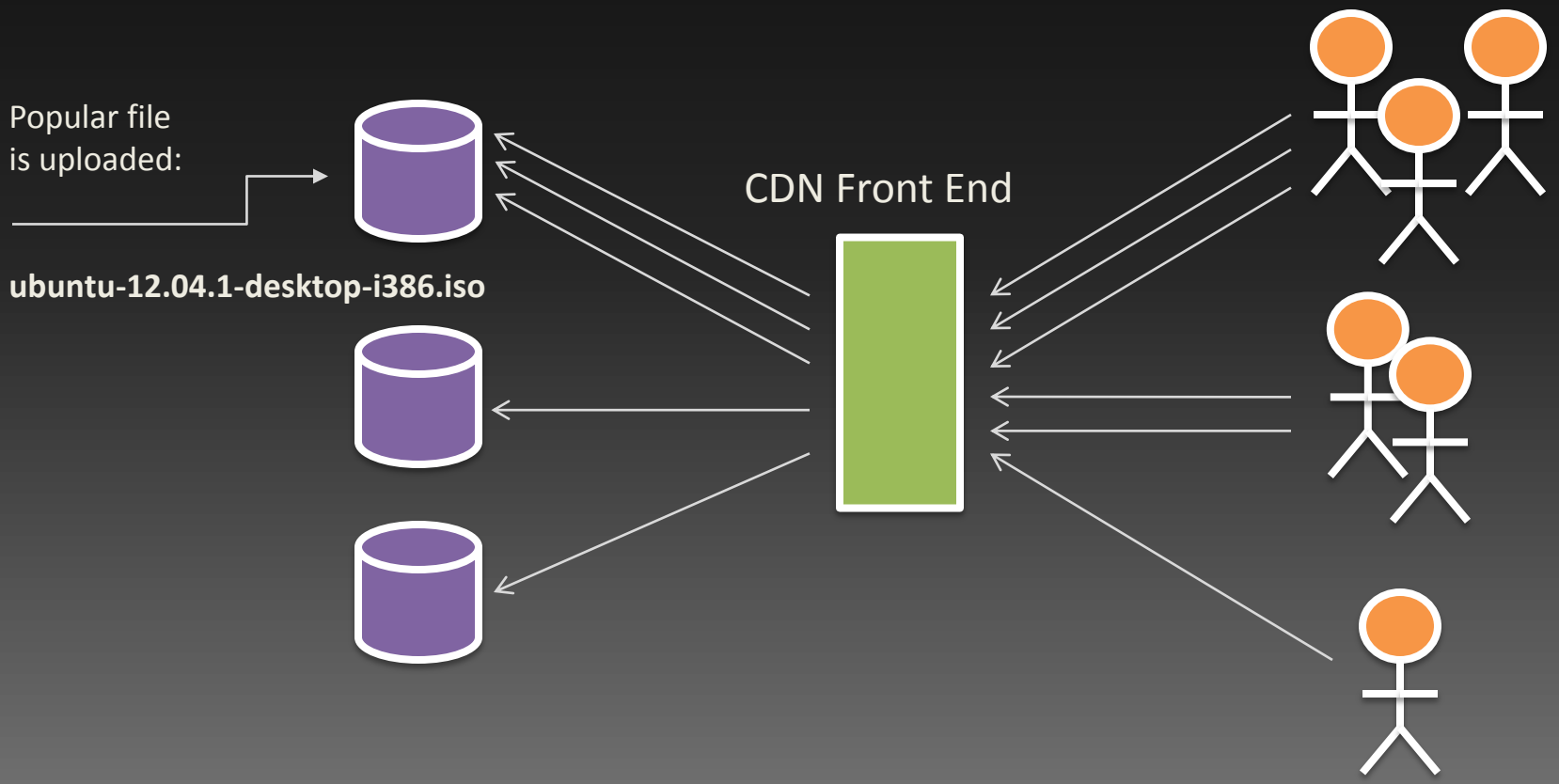
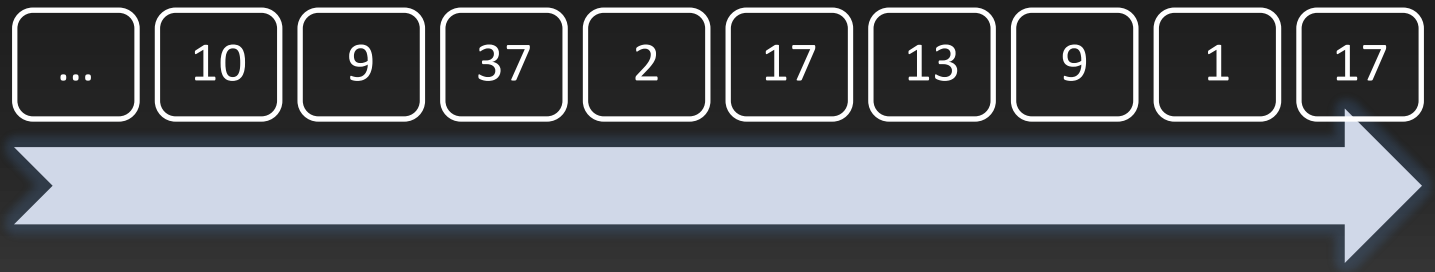
Content Delivery Network Example



Heavy Hitters

Given a stream of integers, find the ones which appear most frequently



In our example we want to find 9 and 17 as the most frequent elements

Space Saving algorithm

- Keep k items and counts initially zero
- Count first k distinct items exactly
- On seeing a new item:
  - If it is already in our set, increment counter
  - If not, replace item with least count, increment count

The algorithm overestimates, when replacing an item we can keep the old counter in our data structure as the "overestimate" value

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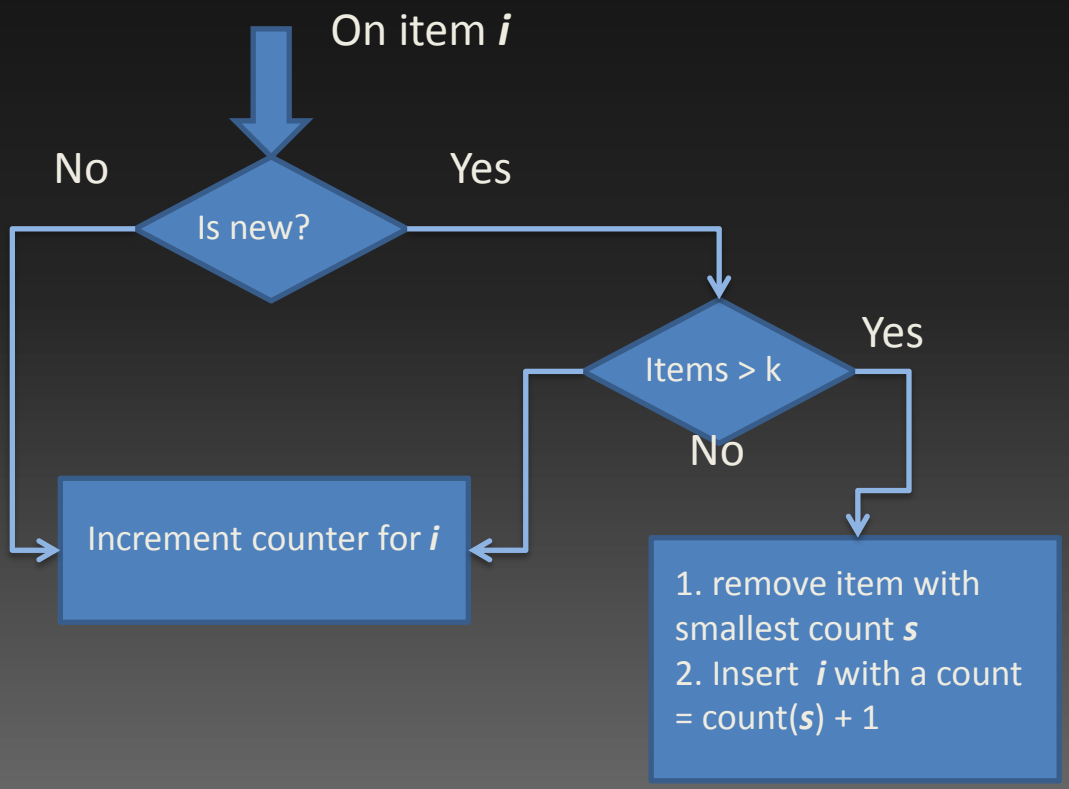
Space Saving algorithm



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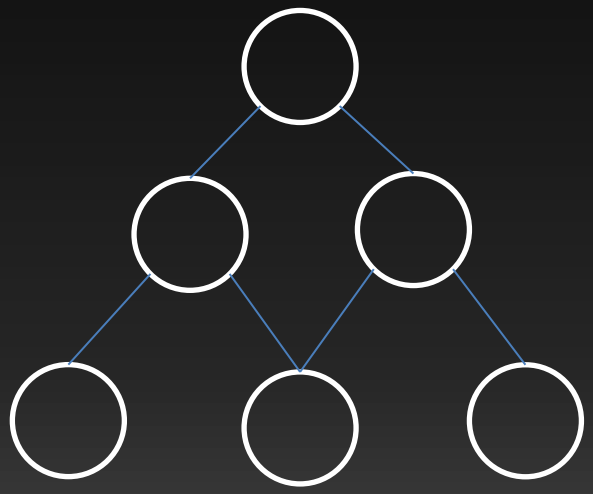

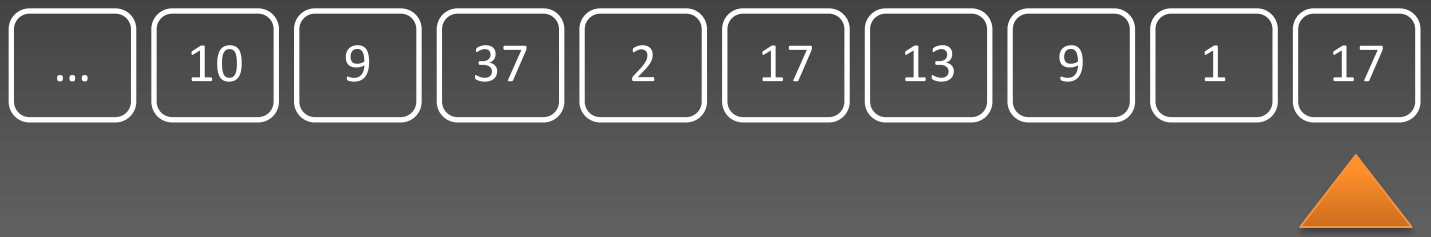

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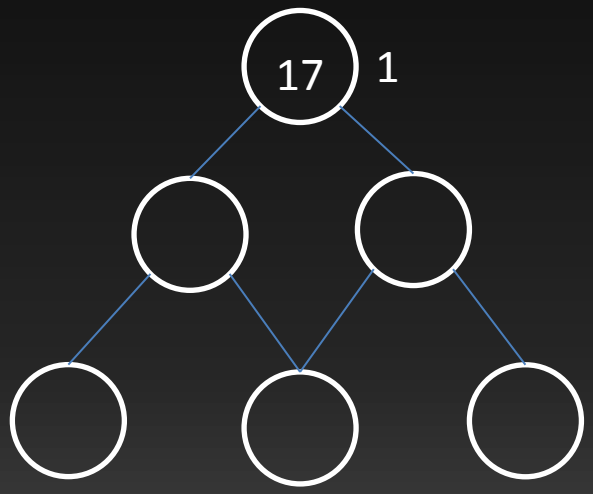

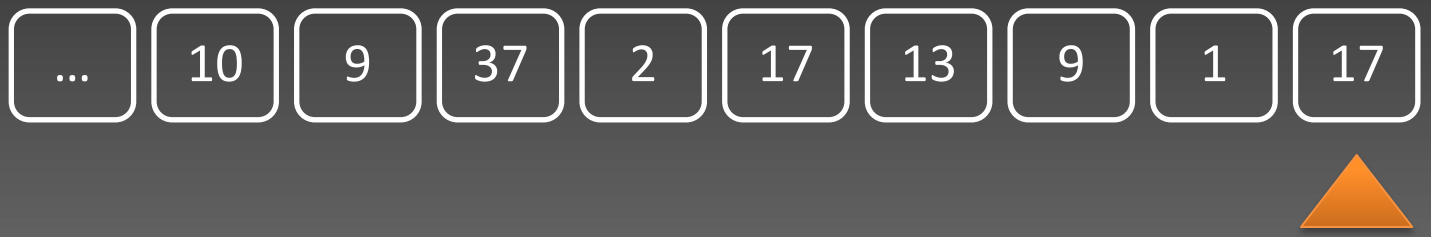

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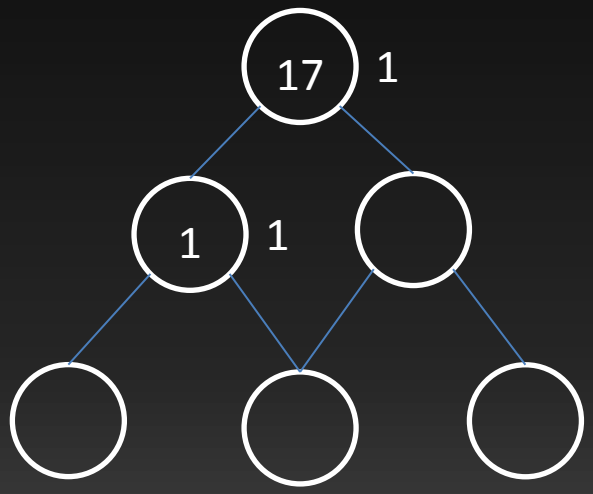

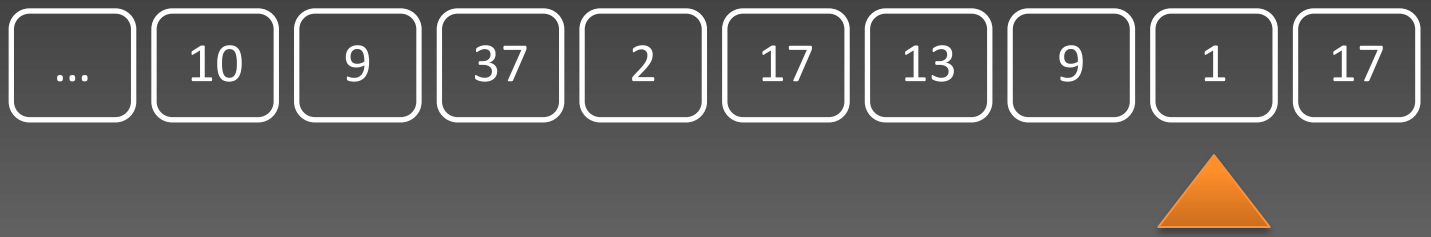

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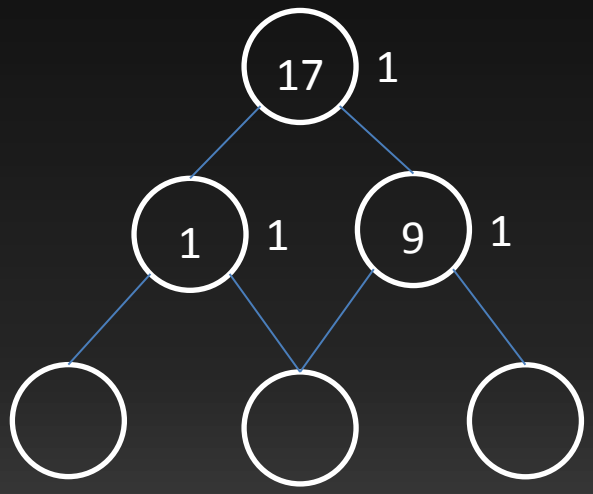

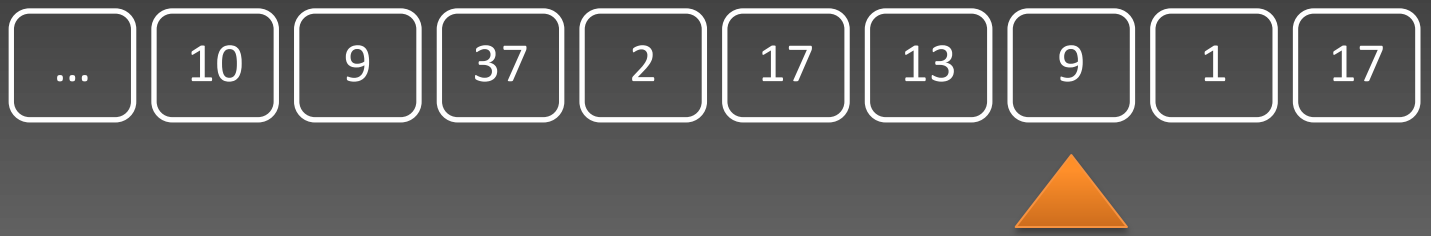

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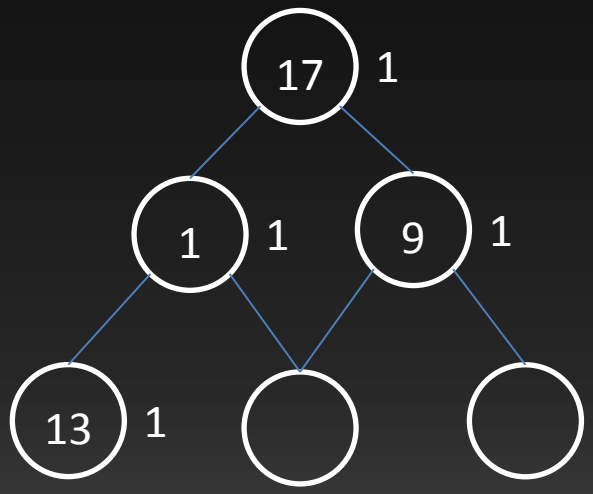

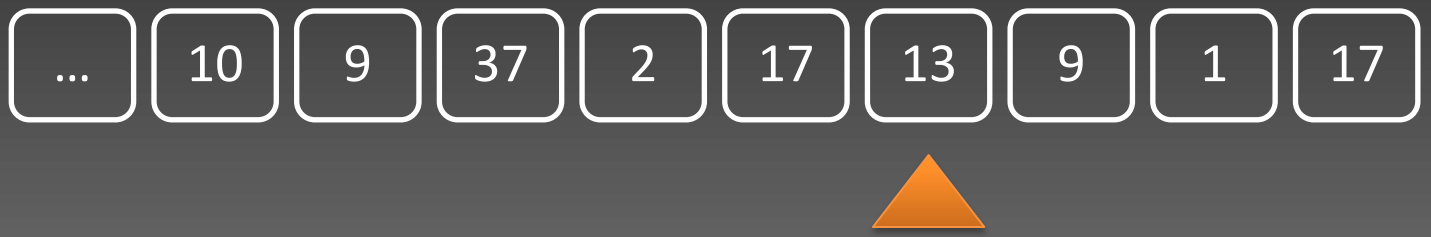

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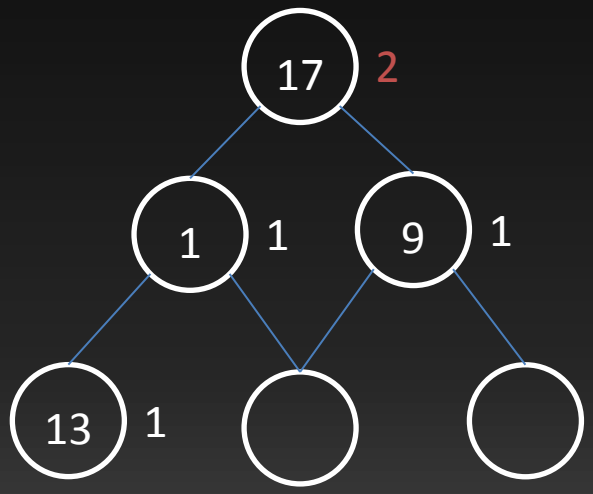

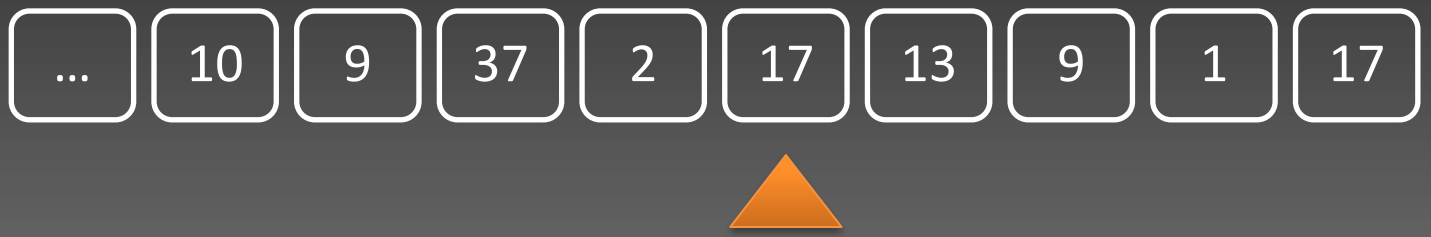

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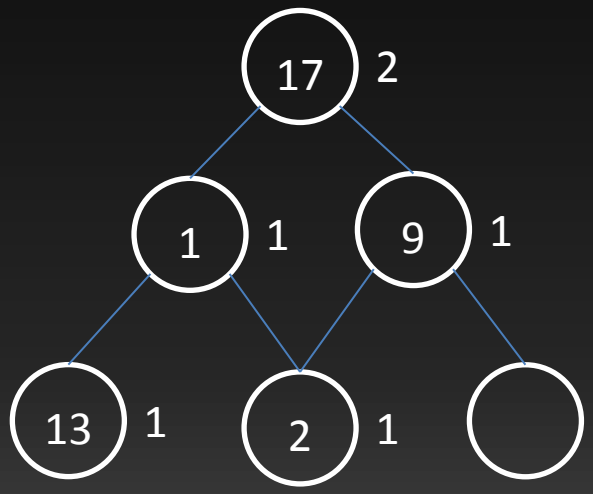

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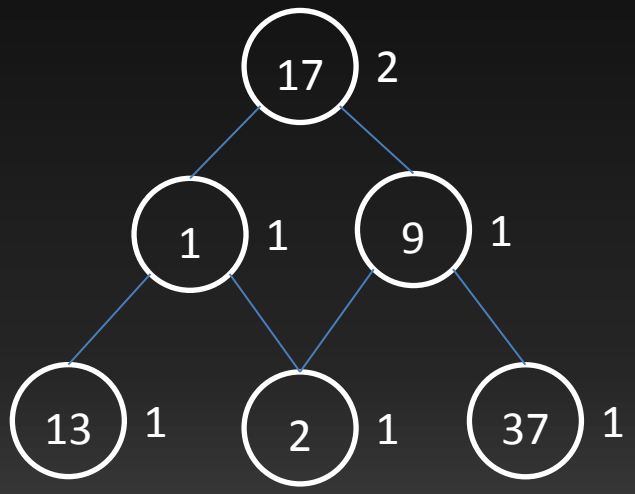

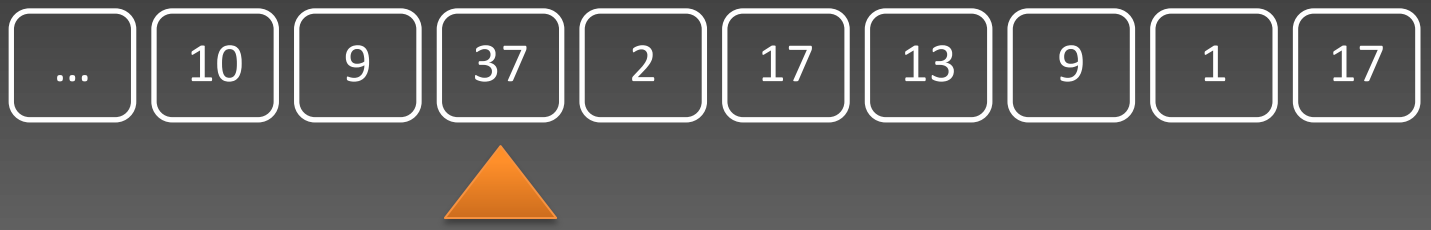

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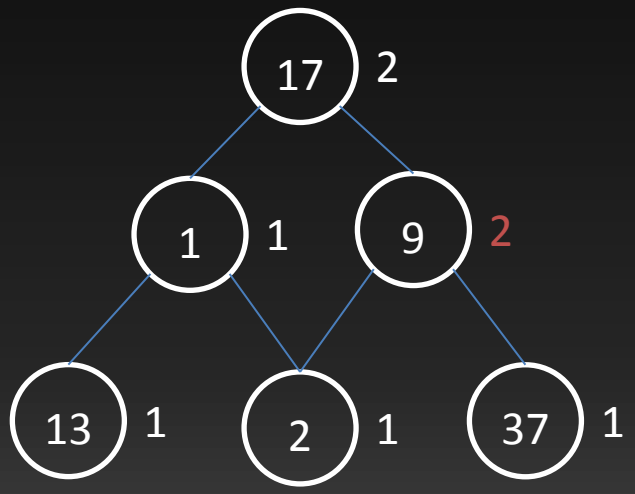

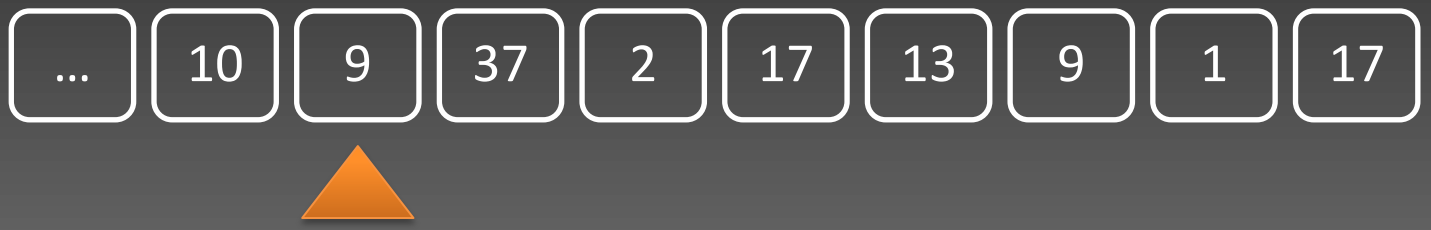

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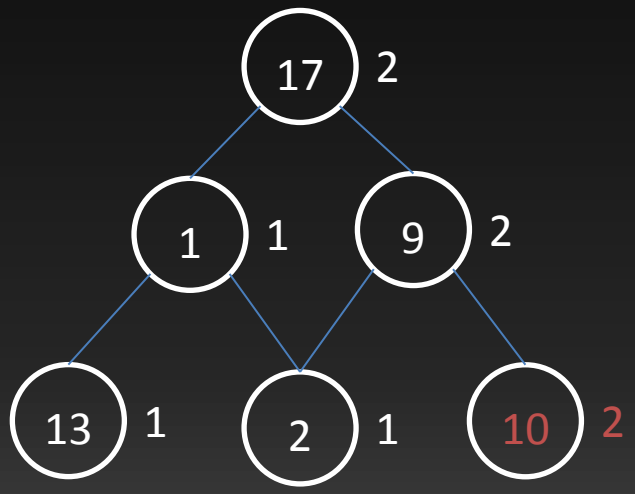

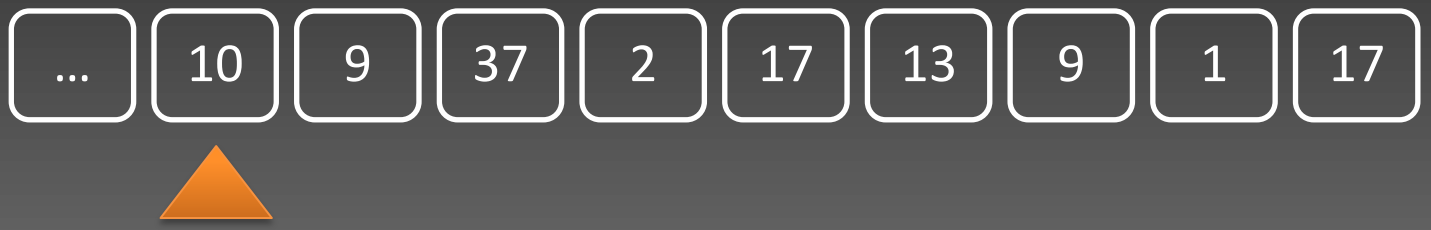

Space Saving algorithm analysis

- Smallest counter value, *min,* is at most *n/k*
- True count of an uncounted item is between *0* and *min*
- Any item x whose true count > *n/k* is stored

- So the algorithm finds all items with counts > *n/k* and the error in counts <= *n/k*

Experimental notes

- Multiple algorithms because this was one of the most studied problems in data streams, but Space Saving is the best performer

- Even for Space Saving we have many implementation details: hashtables to check if an item is in our data set?, heap to find the current minimum?, etc

Experimental notes

- Very fast in practice: ten millions of updates per second
- Very good practical accuracy and memory usage
  - easy to obtain 100% accuracy for real-life data with only a small additional space (usually 1.1 * k)

Extensions

- Weighted items (find items whose total weight is high)
- Support deletion of items (negative weight)
- Heavy Changers (which items have largest change)
- Distinct heavy hitters (which sources contact the most distinct addresses)
- Time Decay (weight of items decay with age)

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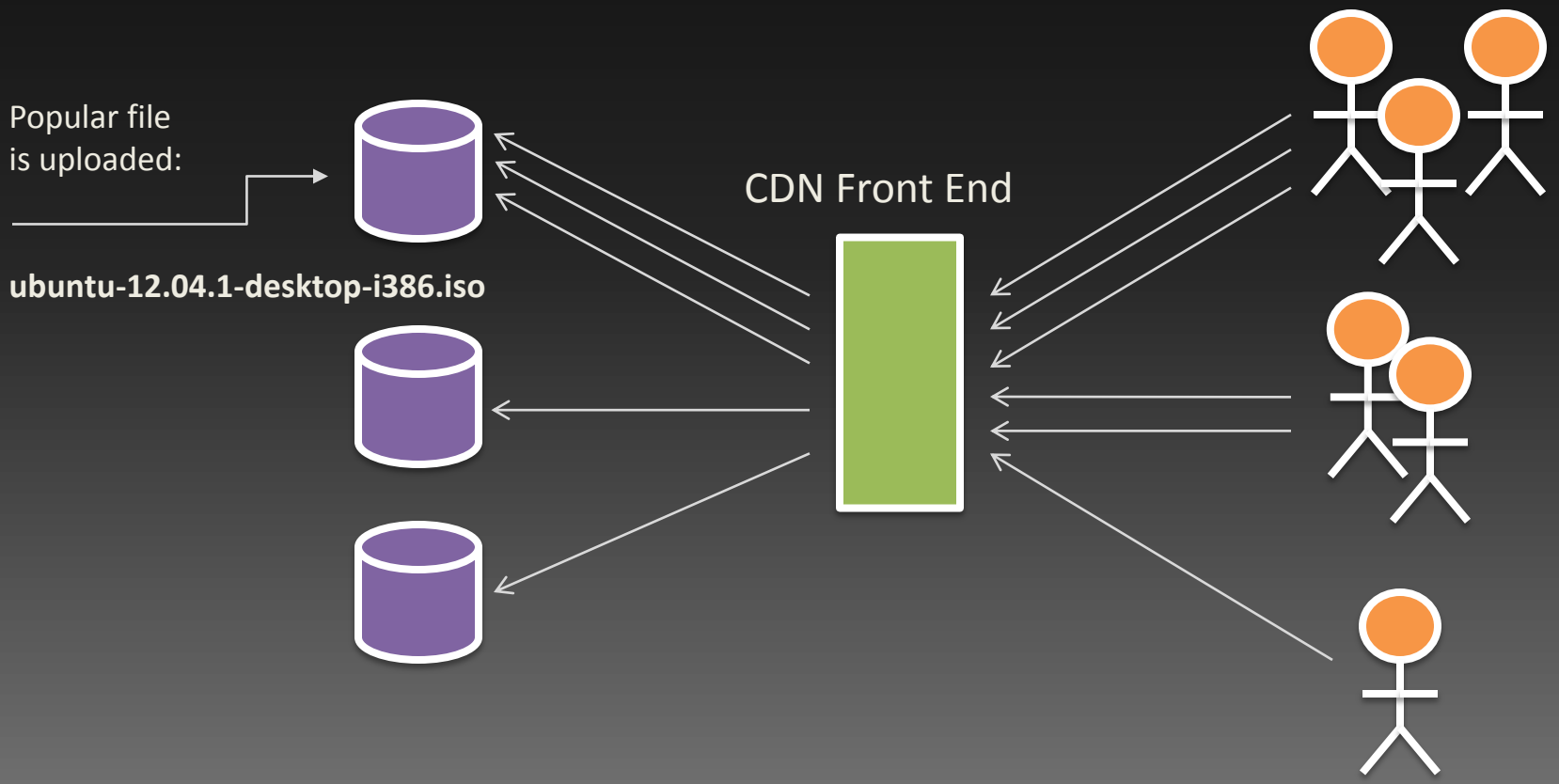
Content Delivery Network Example



Takeaways

- Recent area of research (last 20 years), but increasingly important
- Time and space complexity matter a lot
- Different algorithms make different trade-offs (space vs time vs accuracy)

Learn more…

- "Probabilistic Counting Algorithms for Database Applications" - *Flajolet and Martin (1985)*
- "The space complexity of approximating the frequency moments" - *Alon, Noga; Matias, Yossi; Szegedy, Mario (1999)*
- Data Streams: Models and Algorithms - *Charu C. Aggarwal*
- Implementations of heavy hitters algorithms (and more!) at: *http://www.research.att.com/~marioh/frequent-items*

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Q&A