# External Sampling

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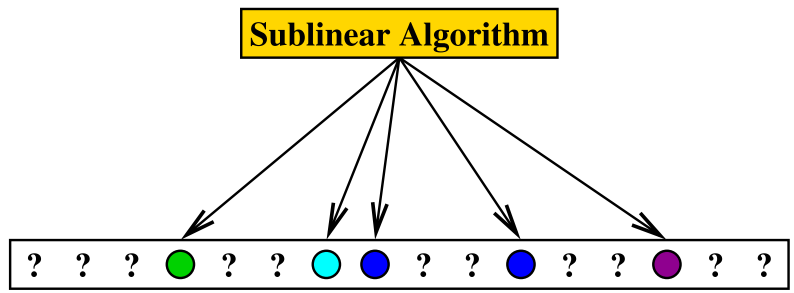
Joint work with **Alexandr Andoni**,
**Piotr Indyk**, and **Ronitt Rubinfeld**

# Massive Data

Various models have been developed:

- Sublinear time algorithms
  (for instance, random sampling)



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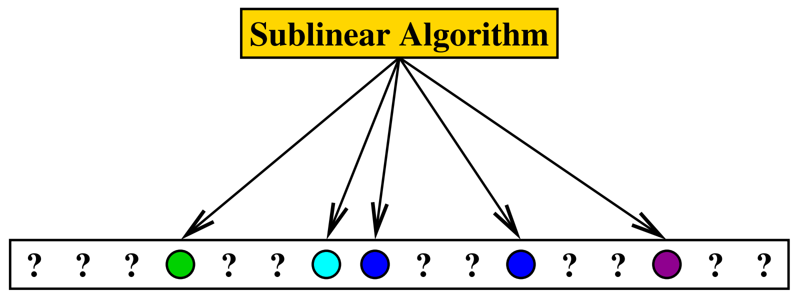
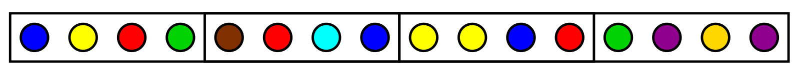



- External memory algorithms for data on disk



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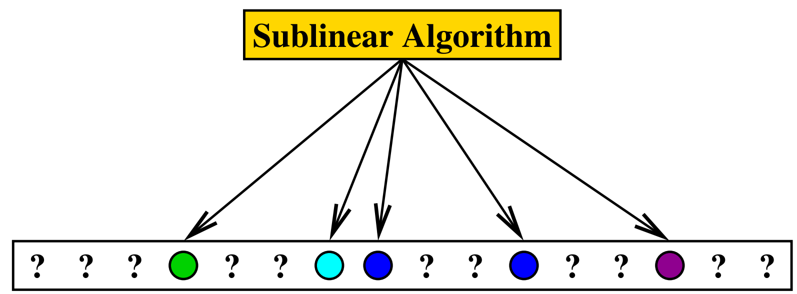


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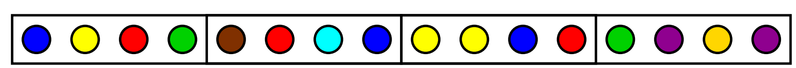
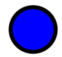
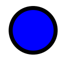
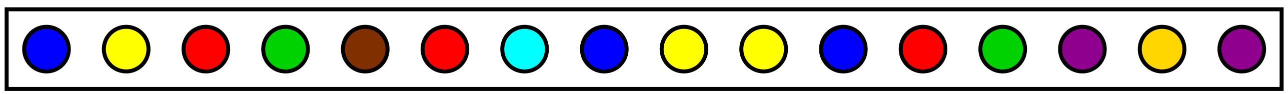


Can combine the two?

- Has to read entire block to get single sample
- Can decrease the number of block reads?

# Estimating frequency

- Problem:
  - if frequency of  $\geq 2f$, report YES
  - if frequency of  $\leq f$, report NO



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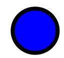
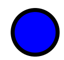
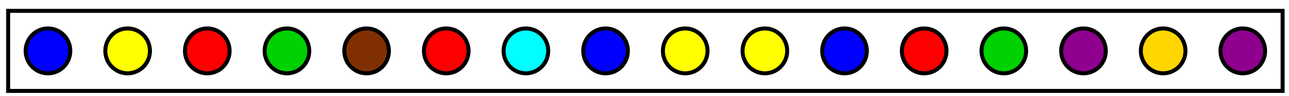
  - if frequency of  $\geq 2f$, report YES
  - if frequency of  $\leq f$, report NO



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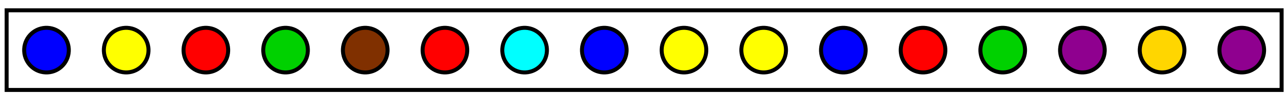

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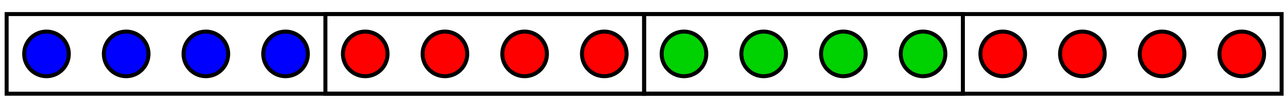
- Sampling blocks doesn't help!



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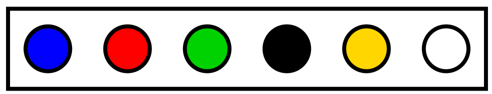
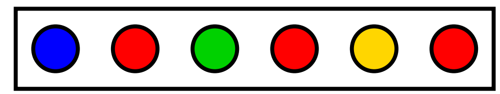
YES:  NO: 

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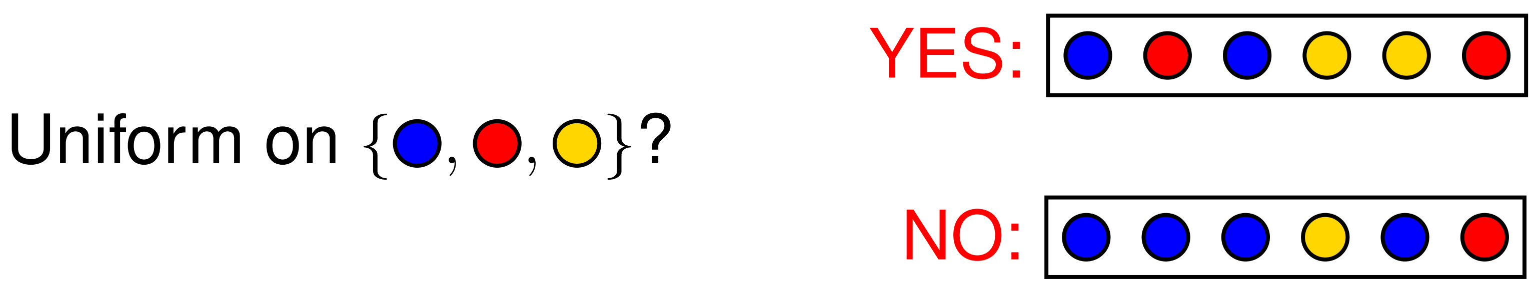

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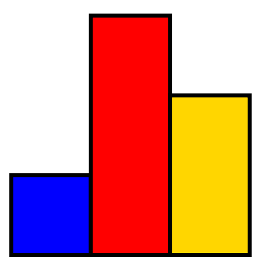
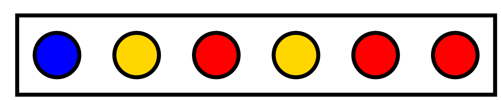
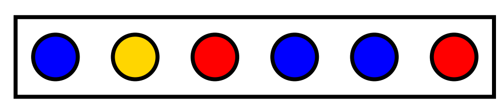
Distributed like  ?

YES: 

NO: 

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- All require $\tilde{\Theta}(\sqrt{n})$ samples for fixed $\epsilon$
- We improve by factor $\tilde{\Theta}(\sqrt{B})$ to $\tilde{\Theta}(\sqrt{n/B})$ block reads
- Can show improvement (nearly) optimal

# Distinctness

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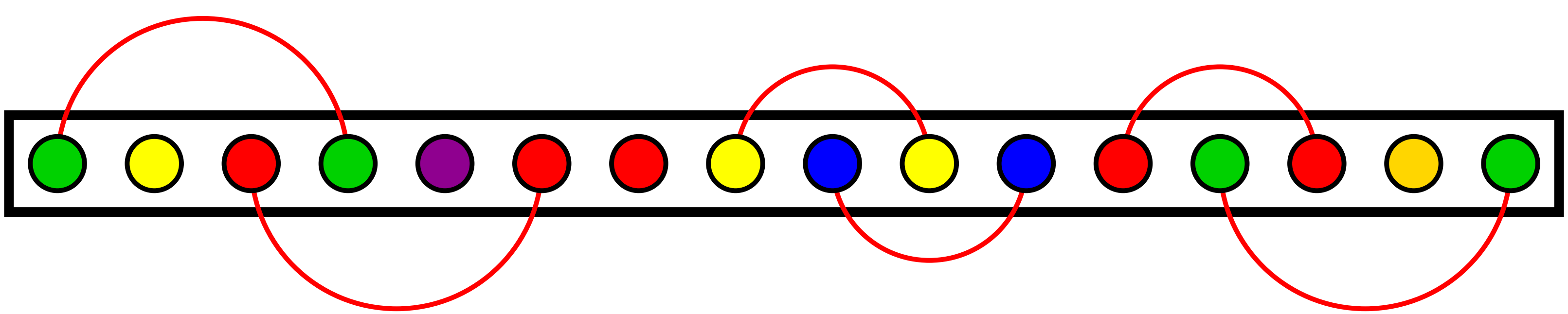
- NO instance:
  - $\Omega(\epsilon n)$ disjoint pairs of identical elements
  - Birthday paradox: algorithm samples one of them with constant probability



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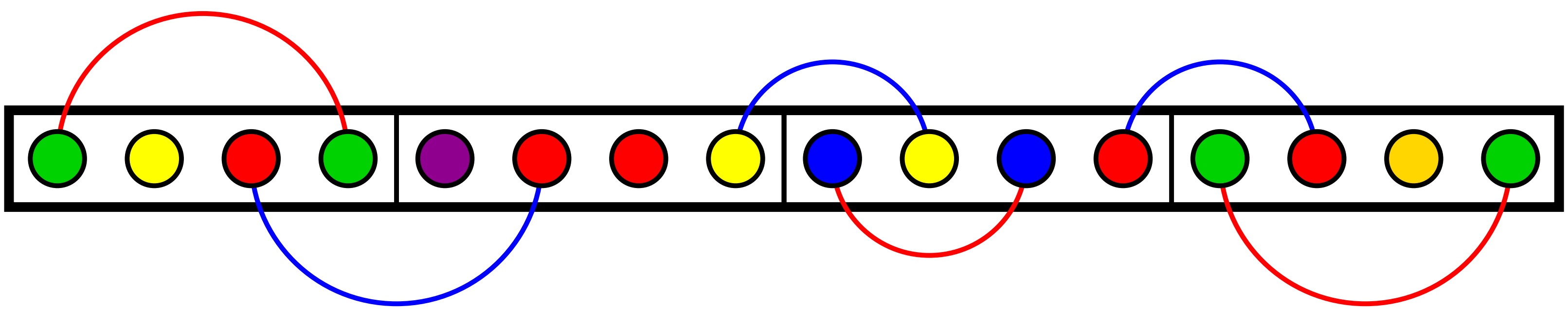

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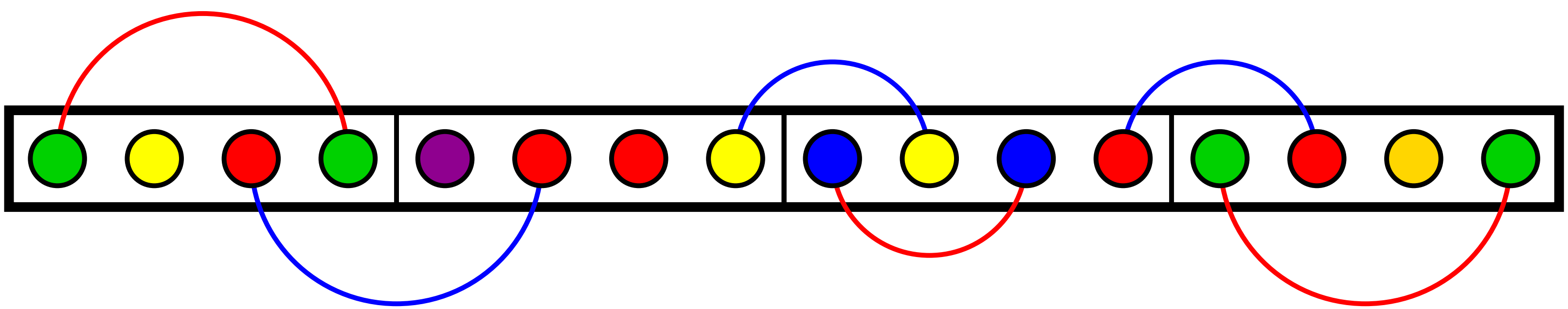

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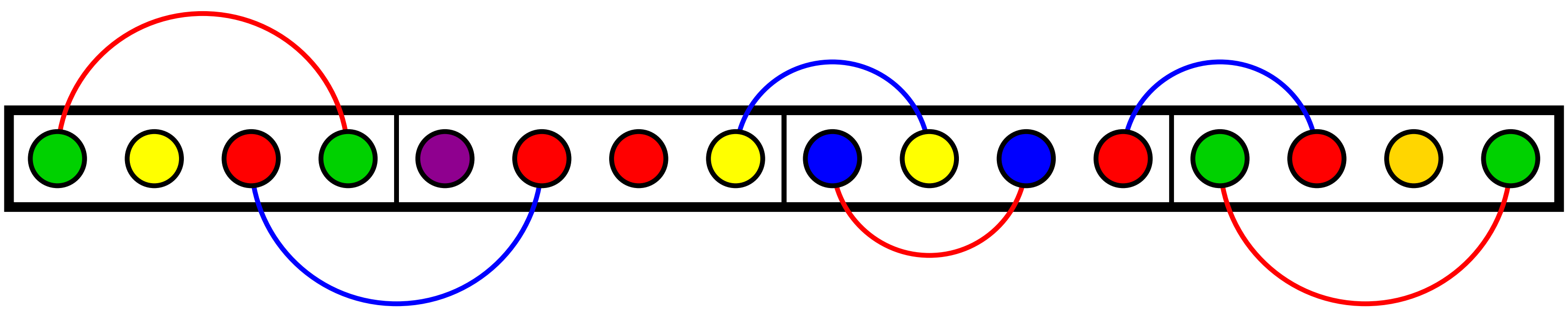

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- Matching lower bound

# Other Problems

# Applications of Our Techniques

- Graph Isomorphism [Fischer-Matsliah]
  - Two graphs: known $G$ and unknown $H$
    - YES: $G$ and $H$ isomorphic
    - NO: $\geq \epsilon n^2$ edges of $H$ must be modified for isomorphism
  - Allowed queries: Is $(u, v)$ edge of $H$?
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- Metric Properties of Points [O.]
  - Does set of points embed into a tree metric? an ultrametric? $\ell_2^d$? $\ell_1^2$? $\ell_\infty^2$?
  - Searching for $k$-tuple
  - Standard algorithms: $\approx O(n^{1-1/k})$ samples for fixed $\epsilon$
  - Block model: $O((n/B)^{1-1/k})$ samples

# Further Problems

- Monotonicity
  - Input: sequence of $n$ numbers
    - YES: monotone
    - NO: must delete $\epsilon n$ elements for monotonicity
  - Can improve from $O(\frac{1}{\epsilon}\log n)$ to $O(\frac{1}{\epsilon}\log(n/B))$

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- OPEN: Equality of Distributions [Batu-Fortnow-Rubinfeld-Smith-White]
  - Input: two sequences on disk
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- Homework:

Check your favorite sublinear algorithm!!!