Paper survey
[1] Unreeling Netflix: Understanding and Improving Multi-CDN Movie Delivery, IEEE Infocom 2012
[2] Algorithmic Nuggets in Content Delivery, ACM SIGCOMM CCR, 2015

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Video Streaming in Practice

- Content placement and client-server matching of video streaming is not simple
- Netflix
  - Uses multiple cloud and CDNs
  - Amazon cloud
  - CDN
    - Akamai
    - Limelight
    - Level3

Hostnames in Netflix

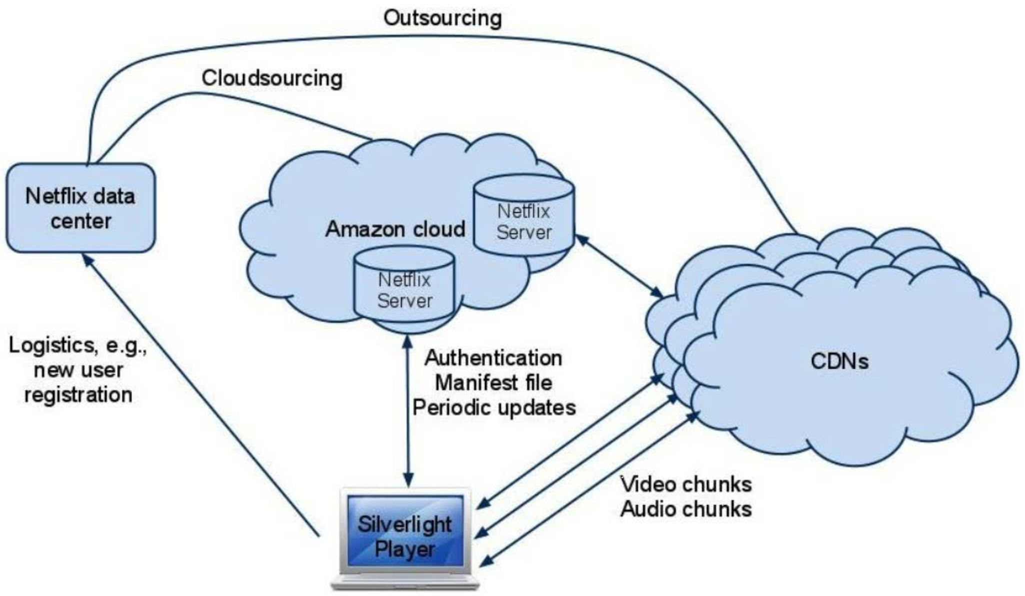


Fig. 1. Netflix architecture

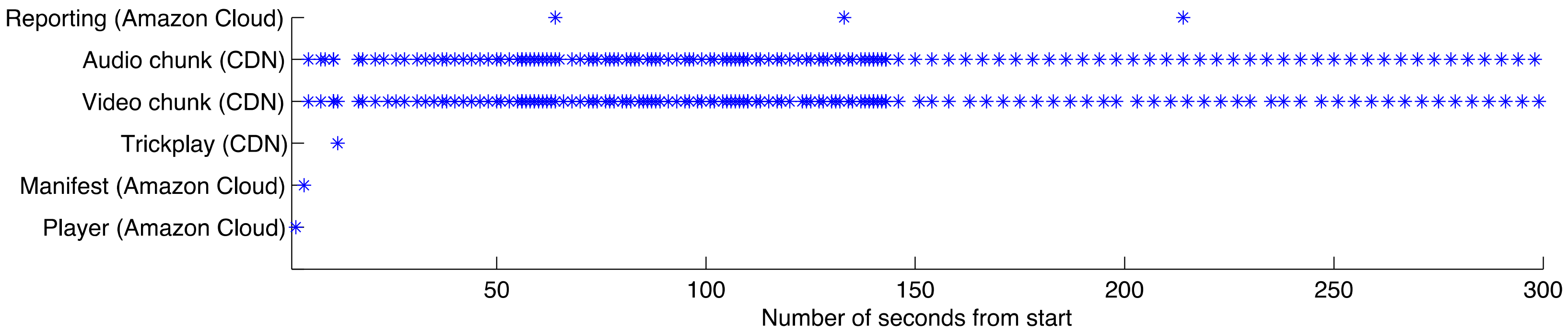
TABLE I
KEY NETFLIX HOSTNAMES

Hostname	Organization
www.netflix.com	Netflix
signup.netflix.com	Amazon
movies.netflix.com	Amazon
agmoviecontrol.netflix.com	Amazon
nflx.i.87f50a04.x.lcdn.nflximg.com	Level 3
netflix-753.vo.llnwd.net	Limelight
netflix753.as.nflximg.com.edgesuite.net	Akamai

Netflix Architecture

- Netflix data center
  - www.netflix.com: registration, redirect to movies.netflix.com or signup .netflix.com
- Amazon cloud
  - Agmoviecontrol.netflix.com and movies.netflix.com
  - EC2, S3, SDB, VPC: Content ingestion, log recording/analysis, DRM, CDN routing, user sign-in, movie device support
- CDN
  - Multiple CDN's: Akamai, Limelight, Level-3
- Players
  - Silverlight, HTML5

Timeline



1. Silverlight player download and user authentication
2. Netflix manifest file
   - Metadata to conduct adaptive video streaming
3. Trickplay
   - Pause, rewind, forward
4. Audio and video chunk downloading
   - 14 different bitrates
5. User experience report
   - Agmoviecontrol.netflix.com

```
<nccp:bitrate>560</nccp:bitrate>
<nccp:videoprofile>
   playready-h264mpl30-dash
</nccp:videoprofile>
<nccp:resolution>
   <nccp:width>512</nccp:width>
   <nccp:height>384</nccp:height>
</nccp:resolution>
<nccp:pixelaspect>
   <nccp:width>4</nccp:width>
   <nccp:height>3</nccp:height>
</nccp:pixelaspect>v
<nccp:downloadurls>
   <nccp:downloadurl>
      <nccp:expiration>131xxx</nccp:expiration>
      <nccp:cdnid>6</nccp:cdnid>
      <nccp:url>http://nflx.i.../...</nccp:url>
   </nccp:downloadurl>
   <nccp:downloadurl>
      <nccp:expiration>131xxx</nccp:expiration>
      <nccp:cdnid>4</nccp:cdnid>
      <nccp:url>http://netflix.../...</nccp:url>
   </nccp:downloadurl>
   <nccp:downloadurl>
      <nccp:expiration>131xxx</nccp:expiration>
      <nccp:cdnid>9</nccp:cdnid>
      <nccp:url>http://netflix.../...</nccp:url>
   </nccp:downloadurl>
</nccp:downloadurls>
```

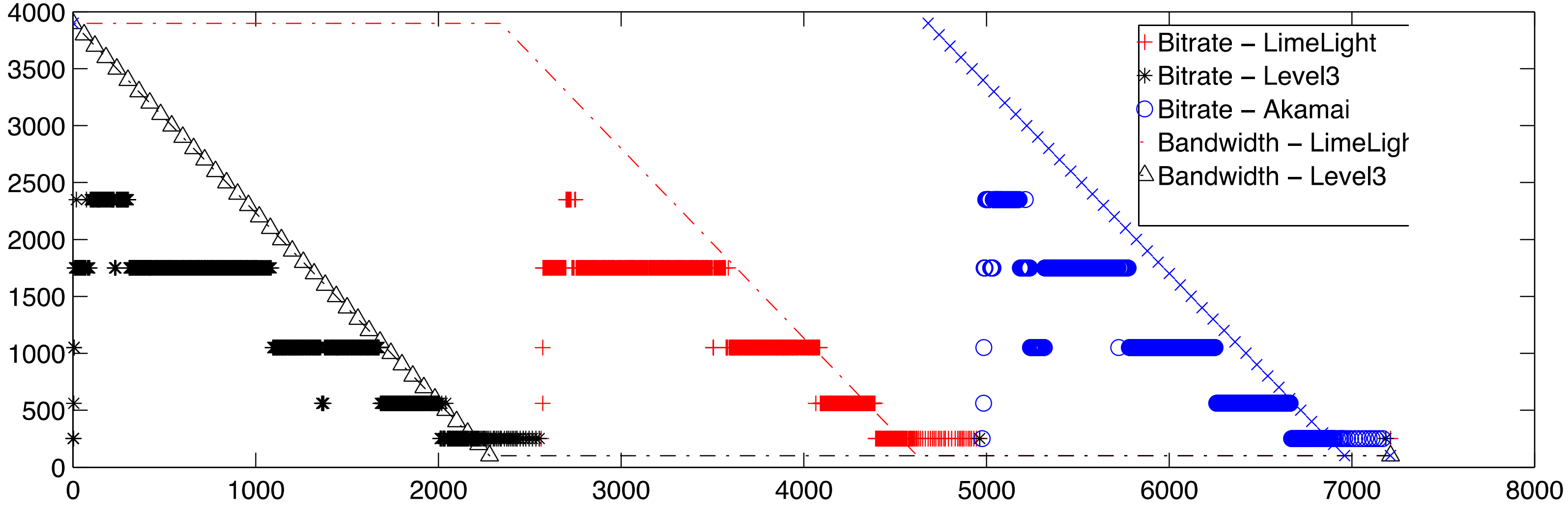

Fig. 4. Video downloadable for one quality level

Manifest File

- CDN ranking and user accounts
  - Only based on user account
- Audio and video bitrates

CDN Selection Strategy

- Experiments with dummynet
  - Throttle the inbound bandwidth to the client
  - 3900Kbps → decrease 100 Kbps every minute → 100 Kbps



Algorithmic Nuggets in Content Delivery

- Akamai's CDN currently has over 170,000 edge servers located in over 1300 networks in 102 countries and serves 15-30% of all Web traffic.
- Stable load balancing
  - Global load balancing is the process of mapping clients to the server clusters of the CDN
  - Map unit
    - (IP address prefix, traffic class)

The Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 2012
Alvin E. Roth, Lloyd S. Shapley

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The Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 2012

Photo: U. Montan
Alvin E. Roth
Prize share: 1/2

Photo: U. Montan
Lloyd S. Shapley
Prize share: 1/2

The Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 2012 was awarded jointly to Alvin E. Roth and Lloyd S. Shapley *"for the theory of stable allocations and the practice of market design"*

COLLEGE ADMISSIONS AND THE STABILITY OF MARRIAGE

D. GALE* AND L. S. SHAPLEY, Brown University and the RAND Corporation

1. Introduction. The problem with which we shall be concerned relates to the following typical situation: A college is considering a set of n applicants of which it can admit a quota of only q. Having evaluated their qualifications, the admissions office must decide which ones to admit. The procedure of offering admission only to the q best-qualified applicants will not generally be satisfactory, for it cannot be assumed that all who are offered admission will accept. Accordingly, in order for a college to receive q acceptances, it will generally have to offer to admit more than q applicants. The problem of determining how many and which ones to admit requires some rather involved guesswork. It may not be known (a) whether a given applicant has also applied elsewhere; if this is known it may not be known (b) how he ranks the colleges to which he has applied; even if this is known it will not be known (c) which of the other colleges will offer to admit him. A result of all this uncertainty is that colleges can expect only that the entering class will come reasonably close in numbers to the desired quota, and be reasonably close to the attainable optimum in quality.

for the applicants as well
his application all other
haps not without reason,
ill be hurting his chances

list," whereby an appli-
y be admitted later if a
an applicant is accepted
r that he prefers. Should
at the second will admit
forming the second and
ts him?
be avoided. We shall de-
which should be satisfac-
d which, assuming there
its quota.

to be assigned among m
plicant ranks the colleges
es which he would never
ssume there are no ties;
e colleges he is neverthe-
ilarly ranks the students
t eliminated those appli-

of Naval Research under Task

PRACTICAL MARKET DESIGN: FOUR MATCHES†

The New York City High School Match

By ATİLA ABDULKADİROĞLU, PARAG A. PATHAK, AND ALVIN E. ROTH*

We assisted the New York City Department of Education (NYCDOE) in designing a mechanism to match over 90,000 entering students to public high schools each year. This paper makes a very preliminary report on the design process and the first year of operation, in academic year 2003–2004, for students entering high school in fall 2004. In the first year, only about 3,000 students had to be assigned to a school for which they had not indicated a preference, which is only 10 percent of the number of such assignments the previous year.

I. The Prior (2002–2003) New York City Matching Procedure

There are seven specialized high schools in New York City whose places are allocated by entrance exam (one by auditions). Rising high-school students (mostly 8th-graders, but some 9th-graders) could also apply to up to *five* other programs, by ranking them on a preference list. (Different high-school programs, with separate applications and admissions, are referred to here, interchangeably, as schools or programs.

Global Load Balancing

- M
  - Client IP prefix
- C
  - Server cluster
- Stable load balancing
  - Stable marriage problem by G ale and Shapley in 1962

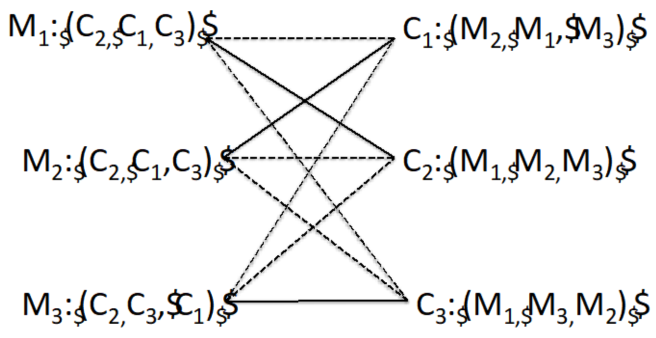
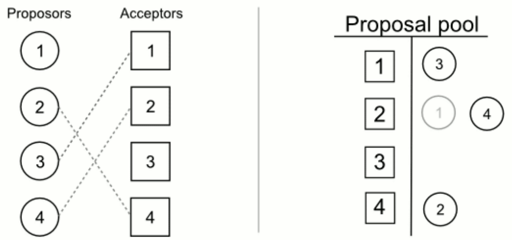


Figure 2: Each map unit has a preference order of clusters from where to download content, while each cluster has a preference order of which map units to serve content. A stable marriage (marked in bold) is a matching of map units to clusters such that no un-matched pair prefer each other over their matched partners.

Round : 1



- 1 accepts 3's proposal – no better offer.
- 2 accepts 4's proposal as 4 is more prefereable to 1.
- 3 recieves no offer.
- 4 accepts 2's proposal – no better offer.

Preferences

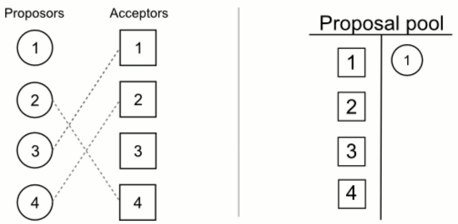
□ → ○ Acceptor Table

1	1	3	2	4
2	3	4	1	2
3	4	2	3	1
4	3	2	1	4

○ → □ Proposor Table

1	2	1	3	4
2	4	1	2	3
3	1	3	2	4
4	2	3	1	4

Round : 2



- 1, the only un-attached member makes its offer to 1, its first preference not previously proposed to.

Preferences

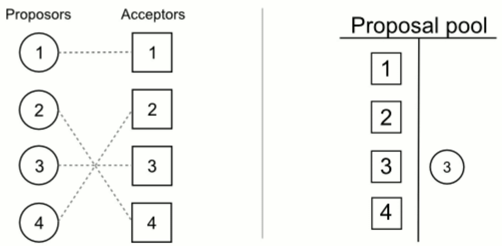
□ → ○ Acceptor Table

1	1	3	2	4
2	3	4	1	2
3	4	2	3	1
4	3	2	1	4

○ → □ Proposor Table

1	2	1	3	4
2	4	1	2	3
3	1	3	2	4
4	2	3	1	4

Round : 3



- 3 accepts 3, not having a better offer

Preferences

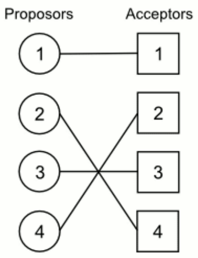
□ → ○ Acceptor Table

1	1	3	2	4
2	3	4	1	2
3	4	2	3	1
4	3	2	1	4

○ → □ Proposor Table

1	2	1	3	4
2	4	1	2	3
3	1	3	2	4
4	2	3	1	4

Finish



- No two members {P,A} would prefer one-another over their current pairing

Preferences

□ → ○ Acceptor Table

1	1	3	2	4
2	3	4	1	2
3	4	2	3	1
4	3	2	1	4

○ → □ Proposor Table

1	2	1	3	4
2	4	1	2	3
3	1	3	2	4
4	2	3	1	4

Implementation challenges

- Complexity and scale
  - Tens of millions of map units and thousands of clusters for over a do zen traffic classes
- Time to solve
  - Map unit assignments should be recomputed every 10 to 30 second s
- Demand and capacity estimation
- Incremental and persistent allocation

Summary

- Content placement and delivery
  - Includes intermediate network elements and clouds
- Algorithm to be implemented
  - Consider the practical environment