Policy Expressivity in the Anzere Personal Cloud

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Microsoft Research\textsuperscript{1}

Systems Group, ETH Zurich\textsuperscript{2}
The problem of personal data replication
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Today, data is manually replicated by the user in an ad-hoc manner.
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Today, data is manually replicated by the user in an ad-hoc manner.
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Today data is replicated in an ad-hoc manner and directly by the user.
The problem of personal data replication

Today, data is manually replicated by the user in an ad-hoc manner.
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The problem of personal data replication

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Online service providers (Facebook, Google, Yahoo) offer many advantages but also many drawbacks:

- Loss of privacy and control
- Lock-in
- Vulnerability to provider failures due to attacks or insolvency
A personal system for managing data

- Preserve growing body of personal data
- Make data available according to flexibly-specified policies
  - Recently-downloaded music on a device carried by the user
A personal cloud system for managing data

- Exploit (and decide when to acquire and release) virtual resources on demand
  - Recent files cached at 100 msec latency from the user’s phone
Challenges

In online, centralized solutions
- Focus on scale and throughput

In personal cloud systems
- Policy flexibility
- Heterogeneity of the device ensemble
- Changing set of devices (failure, theft, purchase of new hardware)
- Limited storage resources on some nodes (phones, tablets)
- Data durability
Hot topic

- Sync tools
  - Microsoft LiveMesh, Dropbox
- Content-based partial replication
  - Cimbiosys and Perspective
- Device transparency
  - Eyo
- Partial replication
  - PRACTI, Ficus
- Flexible consistency
  - PRACTI, Coda, Bayou, TACT
Hot topic

- Sync tools
  - Microsoft LiveMesh, Dropbox
- **Content-based partial replication**
  - Cimbiosys and Perspective
- **Device transparency**
  - Eyo
- Partial replication
  - PRACTI, Ficus
- Flexible consistency
  - PRACTI, Coda, Bayou, TACT, Paxos
- **Anzere:**
  - Expand the expressivity of policies, without sacrificing scalability
Anzere’s key principles

Device-neutral policies

- Based on device predicates rather than names
Anzere’s key principles

Device-neutral policies

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- Replicate photos on my mobile phone to my home server
Anzere’s key principles

Device-neutral policies

- Based on device predicates rather than names
- Replicate photos on my mobile phone to my home server
- Ensure at least one copy of every photo exists on a fixed server I own

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Anzere’s key principles

Device-neutral policies

- Based on device predicates rather than names
- Replicate photos on my mobile phone to my home server
- Ensure at least one copy of every photo exists on a fixed server I own
- Make items modified in the last hour accessible at no more than 100 msec latency from the phone
Anzere’s key principles
Device-neutral policies

- Based on device predicates rather than names
- Replicate photos on my mobile phone to my home server
- Ensure at least one copy of every photo exists on a fixed server I own
- Make items modified in the last hour accessible at no more than 100 msec latency from the phone

Benefits
- Work across changes in the device set
- Automatically apply to new devices (unless radically different)
- Potentially reusable by other users
Anzere’s key principles

Policy stratification

Automatic extraction of metadata

item(flower.jpeg,'JPEG',1272466300,public,…).
device(nokiaN900,mobile,phone,owned,0,…).
Anzere’s key principles
Policy stratification

<table>
<thead>
<tr>
<th>picture_item(Itemid) :-</th>
</tr>
</thead>
<tbody>
<tr>
<td>item{itemid:Itemid,type:'JPEG'};</td>
</tr>
<tr>
<td>item{itemid:Itemid,type:'PNG'}.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>any_device(Resid) :-</th>
</tr>
</thead>
<tbody>
<tr>
<td>device{resid:Resid}.</td>
</tr>
</tbody>
</table>

Item and device predicates

<table>
<thead>
<tr>
<th>item(flower.jpeg,'JPEG',1272466300,public,...).</th>
</tr>
</thead>
<tbody>
<tr>
<td>device(nokiaN900,mobile,phone,owned,0,...).</td>
</tr>
</tbody>
</table>

Item and device metadata
Anzere’s key principles
Policy stratification

<table>
<thead>
<tr>
<th>Item predicates</th>
<th>Relation</th>
<th>Device predicates</th>
</tr>
</thead>
</table>
| picture_item(Itemid) :-
  item{itemid:Itemid,type:'JPEG'};
  item{itemid:Itemid,type:'PNG'}. |
| any_device(Resid) :- device{resid:Resid}. |
| item(flower.jpeg,'JPEG',1272466300,public,...). |
| device(nokiaN900,mobile,phone,owned,0,...). |

Policies

policy([[picture_item],[rep,#>,2],[[any_device]]).
Anzere’s key principles
Policy stratification

- Policies are expressed in **logic programming** (Prolog)
- Applications generate policies on users’ behalf
Make data modified in the last hour accessible at no more than 100 msec latency from the phone

% item_predicate
rec_item(Itemid):- item{id:Itemid,moddate:Moddate}, mod_within(Moddate,3600).

% device_predicate
close_dev(MyDevid,Devid,MaxLatency):- ollink{myid:MyDevid,id:Devid,_latency:Latency}, Latency $< MaxLatency.

% policy
policy([[rec_item]],[repany],[[close_dev,NokiaN900,100]]).
Fault tolerance:

*Video backup on 2 fixed, owned devices*

\[
policy([\text{[video_item]}],[\text{rep,\#}\geq,2],[\text{[fixed_device]}, \text{[owned_device]}]).
\]
Fault tolerance:

- Video backup on 2 fixed, owned devices
  
  \[
  \text{policy}([[\text{video\_item}]],[\text{rep,}\#\geq,2],[[\text{fixed\_device}], \text{[\text{owned\_device}]]}).
  \]

Resource management:

- 5GB free storage on phone
  
  \[
  \text{policy}([[\text{any\_item}]],[\text{size,}\#\leq,5000],[[\text{phone\_device}]])
  \]
Expressivity of the policy language

- Fault tolerance:
  - Video backup on 2 fixed, owned devices
    policy([[video_item]], [rep,#>=,2],[[fixed_device], [owned_device]]).

- Resource management:
  - 5GB free storage on phone
    policy([[any_item]], [size,#=<,5000],[[phone_device]]).

- Privacy:
  - No private items in the cloud
    policy([[private_item]], [repnone],[[cloud_device]]).
Anzere system architecture

Office network
Home network
Application policies
Overlay network
Sensors
Data replication (PRACTI, Paxos)
copy & delete actions
acquire & release VM
Reasoning engine (ECLiPSe CLP)
KB
Actuators
Overlay network

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Reasoning engine
- Policies
- Acquire & release VM
- Copy & delete actions

Office network
- Home network

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Policy Expressivity in the Anzere Personal Cloud  
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Policy evaluation
Constraint satisfaction problem
Policy evaluation
Constraint satisfaction problem

Current data distribution

<table>
<thead>
<tr>
<th></th>
<th>phone</th>
<th>home PC</th>
<th>laptop</th>
</tr>
</thead>
<tbody>
<tr>
<td>i1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>i2</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>i3</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>i4</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

#rep
- \( \geq 1 \)
- \( \geq 1 \)
- \( \geq 1 \)
- \( \geq 2 \)

size
- freemem
- \( \geq 2 \)G
- --
- --

constraints
Policy evaluation
Constraint satisfaction problem

Current data distribution

<table>
<thead>
<tr>
<th>phone</th>
<th>home PC</th>
<th>laptop</th>
<th>#rep</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>≥1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>≥1</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>≥1</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>≥2</td>
</tr>
</tbody>
</table>

size
freemem >2G | -- | -- |

Set of solutions

<table>
<thead>
<tr>
<th>phone</th>
<th>home PC</th>
<th>laptop</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>{0,1}</td>
<td>{0,1}</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>phone</th>
<th>home PC</th>
<th>laptop</th>
<th>#rep</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>≥1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>≥1</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>≥1</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>≥2</td>
</tr>
</tbody>
</table>

size
freemem >2G | -- | -- |

Set of solutions

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<thead>
<tr>
<th>phone</th>
<th>home PC</th>
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</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>{0,1}</td>
<td>{0,1}</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Constraints

Execution plan

copy (i2, phone, homePC)
delete (i2, phone)
copy (i4, homePC, laptop)

New data distribution

<table>
<thead>
<tr>
<th>phone</th>
<th>home PC</th>
<th>laptop</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
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Home network
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KB

Application

Actuators

Overlay network

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Reasoning engine (ECLiPSe CLP)

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Office network
Home network
Actuators
Overlay network

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Acquirable resources

Factor the decision of acquiring cloud resources in the policy process

- Evaluate the states the system can achieve through acquirable resources

<table>
<thead>
<tr>
<th>items</th>
<th>constraints</th>
<th>devices</th>
<th>constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>i1</td>
<td></td>
<td>phone</td>
<td>0 {0,1} {0,1}</td>
</tr>
<tr>
<td>i2</td>
<td></td>
<td>laptop</td>
<td>{0,1}  {0,1}</td>
</tr>
<tr>
<td>i3</td>
<td></td>
<td>cloud?</td>
<td>{0,1}   {0,1}</td>
</tr>
<tr>
<td>i4</td>
<td></td>
<td></td>
<td>0 1 0</td>
</tr>
</tbody>
</table>

- acquire and release actions

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Experimental evaluation

- **Testbed**
  - Home PC, Office PC, N900 phone, laptop, PlanetLab VMs, EC2 VMs

- **Policy sustainability**
  - Scales to large numbers of items
  - Low memory consumption: upper bound memory for 10000 items is 64 MB

- **Reactivity**
  - to device changes (e.g., home server crash)
  - to policy changes
  - to device mobility
Experimental evaluation

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Scalability

CLP solver execution time vs. number of items

ECL$^i$PS$^e$ solver, 10 policies
Item equivalence classes

- Generated from the item predicates of the active policies
- \[ \text{policy}([\text{music\_item}], [\text{rec\_item}], [\text{repany}], [\text{owned\_dev}]) \].
  \[ \rightarrow (\text{music\_item}, \text{rec\_item}), (\neg \text{music\_item}, \text{rec\_item}), (\text{music\_item}, \neg \text{rec\_item}), (\neg \text{music\_item}, \neg \text{rec\_item}) \]
- Reduce the problem space

<table>
<thead>
<tr>
<th>equiv classes</th>
<th>c4</th>
<th>c3</th>
<th>c2</th>
<th>c1</th>
</tr>
</thead>
<tbody>
<tr>
<td>devices</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>phone</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>home PC</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>laptop</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
Scalability

CLP solver execution time vs. number of items

- **ECL$^i$PS$^e$** solver, 10 policies
Scalability

CLP solver execution time vs. number of items

![Graph showing CLP solver execution time vs. number of items]

- ECL$^i$PS$^e$ solver, 10 policies
Scalability

CLP solver execution time vs. number of items

- Scale with the policies’ complexity
Conclusion

- Anzere
  - Personal cloud system for data management
  - Supports policy-based replication
  - Scales to large numbers of data items
  - Integrates acquirable resources from the cloud

- It is an actual system
  - Trials on personal clouds: home and office PCs, N900 phones, laptops, PlanetLab and Amazon EC2
  - Source code at www.systems.ethz.ch/research/projects/anzere
Backup slides
Experimental evaluation

- **Testbed**
  - Home PC, Office PC, N900 phone, laptop, PlanetLab VMs, EC2 VMs

- **Policy sustainability**
  - Scales to very large numbers of items (shown before)
  - Low memory consumption: upper bound memory for 10000 items is 64 MB

- **Reactivity**
  - to device changes (e.g., home server crash)
  - to policy changes
  - to device mobility (policy([[picture_item],[mod_item,#<,86400]], [rep,#>=,1], [[fixed_device],[close_device,’laptop’,100]]))
Reactivity
to device failures: home server crash

Acquirable resources help the system stabilize and decrease its level of vulnerability
Reactivity
to mobility: laptop moves from EU to US

![Chart showing reactivity to mobility](chart.png)

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Reactivity
to mobility: laptop moves from EU to US

policy([[picture_item],[mod_item,#<,86400]], [rep,#>=,1],
[[fixed_device],[close_device,'laptop',100]]).

- Acquirable resources allow for improved performance
Optimization overhead

Time vs. number of items for an increasing number of policies
Baseline
Message overhead vs. consistency level

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Baseline
Message overhead vs. consistency level

Bandwidth utilization (kbit/s)

Consistency level

Overlay msg
Sensor msg
Paxos msg
Inval+control msg

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A realistic dataset

<table>
<thead>
<tr>
<th>Data</th>
<th>HomePC</th>
<th>Laptop</th>
<th>OfficePC</th>
<th>Phone</th>
<th>Camera</th>
<th>Cloud</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photos</td>
<td>6958</td>
<td>3291</td>
<td>0</td>
<td>89</td>
<td>25</td>
<td>4492</td>
<td>9231</td>
</tr>
<tr>
<td></td>
<td>8.1G</td>
<td>7.2G</td>
<td>0</td>
<td>38.5M</td>
<td>56.5M</td>
<td>5G</td>
<td>13.2G</td>
</tr>
<tr>
<td>Music</td>
<td>4904</td>
<td>932</td>
<td>3997</td>
<td>868</td>
<td>0</td>
<td>0</td>
<td>4904</td>
</tr>
<tr>
<td></td>
<td>23.1G</td>
<td>5.7G</td>
<td>1.9G</td>
<td>4.3G</td>
<td>0</td>
<td>0</td>
<td>23.1G</td>
</tr>
<tr>
<td>Videos</td>
<td>53</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>28</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>4.7G</td>
<td>2.2G</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>435M</td>
<td>6.8G</td>
</tr>
</tbody>
</table>

number and size of files
Acquirable resources

New issues

- **How many** acquirable resources to reason about?
  - depends on the maximum number of replicas in policies
- **Which** virtual resources to consider?
  - Differ in location, price, cloud providers, ...
- Follow changing **price structures** of cloud providers
Policy set

1. recent music on phones
policy([[audio_item], [mod_item,#<,86400], [repall], [[phone_device]])

2. photos on any fixed device
policy([[picture_item]], [repany], [[fixed_device]])

3. music on more than two personal devices
policy([[audio_item]], [rep,#>=,1], [[pc_device]])

4. videos on any home device
policy([[video_item]], [repany], [[home_device]])

5. public items on at least 2 devices
policy([[public_item]], [rep,#>=,2], [[any_device]])

6. private items on at least 2 fixed devices
policy([[private_item]], [rep,#>=,2], [[fixed_device]])

7. video items recently modified on at least one mobile device
policy([[video_item], [mod_item,#<,86400], [rep,#>=,1], [mobile_device]])

8. photos in the cloud
policy([[picture_item]], [repany], [[cloud_device]])

9. videos on a fixed device at 1-minute latency from the laptop
policy([[video_item], [mod_item,#<,86400], [rep,#>=,1], [[fixed_device], [close_device,'laptop1',100]])

10. no private items in the cloud
policy([[private_item]], [repnone], [[cloud_device]])

11. public photos in the cloud
policy([[public_item], [picture_item]], [repany], [[cloud_device]])
CLP memory consumption

![CLP memory consumption graph]

- Stack peak
- Heap used
- Memory usage upbound

Stack size (MB)

Number of items

Memory usage upbound

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Steady-state tradeoffs
Item vulnerability vs. CLP solving period

- A phone takes 5 photos every 2 minutes (interleaved of 20 s)