# Mathematical Models of Information Preservation

James Cheney

Joint work-in-progress with Bill Arms, Peter Botticelli, Carl Lagoze

Information Science Seminar

December 14, 2000

# Purpose of this talk

- Describe approaches to understanding digital preservation
- Present mathematical modeling approaches based on information theory and logic/semantics
- Discuss *extremely simple*, basic model of information, plans, and policies
- Discussion and feedback important—please ask questions!

## Traditional materials preservation

Traditional materials are:

- expensive to create
- and hard to copy exactly
- but change slowly

Preserve information by preserving *artifacts*

Climate control, acid-free paper, microfilm, etc.

Librarians and archivists know how to do this

## Digital preservation

Digital materials are:

- cheap to create
- and easy to copy
- but constantly changing

Preserving artifacts (like obsolete computers) not practical

Several layers of interpretation (computers, programs, file formats)

Far too much raw data to preserve all of it

No one knows how to do this...

so we are in danger of forgetting digital information

## What is information preservation?

Three views contribute to this work:

- Information theory view: Preserve bits; may care more about some bits
- Digital library view: Protect information of continuing value for access in present and future
- Programming languages view: preserve program behavior (simulation/compilation)

My goal: Argue that PL view can contribute to understanding problem

# Why mathematical modeling?

Approach: understand preservation from first principles, not particular situations

- Identify inputs/unknowns that need to be measured
- Analyze preservation strategies qualitatively and quantitatively
- Understand simple situations, then "scale up" to complex ones
- Get a fresh view of problem—thought experiments

## Simple model I: statics

At a given instant, world has three kinds of things

1. Physical *objects*: rocks, books, floppy disks, palm pilots
2. Abstract *information*: words, $\pi$, *Hamlet*, *Star Wars*
3. *Agents*: people, organizations, “stakeholders”

Also, *environment* in which all this takes place

## Simple model II: local dynamics

At a given instant, things can interact as follows

1. Agents interpret ("see") information in objects
2. Agents can act on objects
3. Environment events can act on objects

Nothing can act *directly* on information; agents can only "see" it indirectly in objects—shades of Plato's Ideal vs Real.

# Defining preservation I: Naive formulation

First, define access: $A$ can access $I$ if there is some object $x$ that $A$ interprets as $I$.

Naive definition of preservation in this model:

Preserving $I$ from $t_0$ to $t_1$ means $A$ can access $I$ from $t_0$ to $t_1$

Preserving $\{I_1, \ldots, I_n\}$ means preserving each $I_j$.

## Defining preservation II: Oversimplifications

Problems with the naive definition:

- Space of physical objects contains all *possible* objects, not all realized ones
- Hence, need to remember *what objects exist*
- Furthermore, there might be confusion at $t_1$ about what $x$ meant what $I$
- Hence, need to remember *what object means what*

# Defining preservation III: Labels

Add “labels” to model.

- Labels are mapped to *specific* physical objects.
- Labels are indestructible
- Labels can be rebound by agent action: $L$ maps to $x_1$ now, not $x_0$

This is kind of a hack...

These seem somewhat related to metadata and identifiers/URNs, but let’s ignore that.

## Defining preservation IV: Getting it right

$A$ can *access* $I$ at $L$ at $t$ if $L$ maps to $x$ at $t$ and $A$ interprets $x$ as $I$.

$I$ is *preserved* for $A$ at $L$ from $t_0$ to $t_1$ if $A$ can access $I$ at $L$ at any $t$ between $t_0$ and at $t_1$.

OK?

In this *extemely simplistic* situation, we now know what preservation *is*.

But not *how* to do it.

## Preservation plans I: Why bother?

Preservation doesn't just *happen*.

Realistic environment events include

- *gradual decay*: e.g. cosmic rays, bit rot, transmission error
- *catastrophic loss*: e.g. HDD crash, library fire, `rm -r *`

causing labeled objects to "drift" over time

Doing nothing is not a good strategy. . .

# Preservation plans II: Questions

But it *is* a strategy (and a pretty cheap one)

What other strategies are there?

First we need to know:

- What actions can agents do and what are their costs and likelihoods of success?
- What events can happen and how likely are they?
- What resources do we have?

# Preservation plans III: Plans as programs

Given answers to all these questions, we can make plans

*Preservation plans* are formal statements of such plans of action:

- Base agent actions: "A does a"
- Sequences: "do this, then do that"
- Conditionals and tests: "if this happens, do that"
- Loops/quantifications: "Do this to everything in this set"

A plan is a sequence of instructions

*Plans are like programs*

# Preservation plans IV: Evaluating plans

What does a plan accomplish?

What resources does it require?

Find out by

1. *Testing*: Run it and see. (Perhaps many times).
2. *Analysis*: Analyze it and predict.

Does it accomplish our goals?

What *are* our goals?

# Preservation policies I: Program specifications

In computer programming, goals are expressed as *specifications*

Example: “Rearrange array elements in increasing order”

Many programs can accomplish given specification

Approach: Treat preservation plans and goals like programs and specifications

Introduce *preservation policies*: a formal statement of preservation goals

## Preservation policies II: Simple goals

Two simple goals: "Preserve Everything", "Preserve Nothing"

Problems with these goals:

- Too absolutist: neither is a realistic goal
- Finite budget: need to prioritize based on information value

How can we express more reasonable policies?

## Preservation policies III: Policies as specifications

Policies might contain the following:

- Preserve $I$ for $A$ at $L$
- Accomplish this subpolicy AND that subpolicy
- Accomplish this subpolicy OR that subpolicy
- IF this subpolicy succeeds, THEN accomplish that subpolicy

*Policy languages are like specification languages*

# Preservation policies IV: Evaluating policies

Questions relating policies and plans:

- What does a plan cost?
- What policies does a plan accomplish?
- Does a plan accomplish a policy?
- What's the least expensive plan that accomplishes a policy?

## Conclusions

Given physical space, information space, agent interpretations and actions, and environment, we can model:

- what preservation *is*
- what plans are *possible* and what they *cost*
- what policies can be accomplished

We believe that this foundation can support reasoning about more complex, realistic preservation situations.

# Things I'm ignoring/glossing over

- Multiple agents with different agendas and beliefs
- Fuzzy preservation criteria—image similarity, etc.
- Physical objects that work together to give access to information
- Change in environment and agents
- Intellectual property, security

Claim: Can add these as natural generalizations