SOFTWARE ENGINEERING FOR

CONNECTION SERVICES

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PART ONE:

CONNECTION SERVICES

AND THEIR SOFTWARE PROBLEMS
THE CONTEXT OF A CONNECTION SERVICE

network domain with a connection-oriented protocol

connection request is routed by routing mechanism of domain

client

source = s
target = t

source = u
target = v

source = y
target = z

address in address space of domain

address in address space of domain
A CONNECTION SERVICE . . .

. . . ENHANCES BASIC CONNECTION PROTOCOLS, SO THEY ARE EASIER TO USE AND HAVE MORE VALUE FOR THEIR USERS

connection service is implemented by servers

all clients and servers use the connection protocol as peers!
## CONNECTION SERVICES: EXAMPLES

<table>
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<tr>
<th>PURPOSE</th>
<th>PRIMARY DATA OR MEDIA OF CONNECTIONS</th>
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<td>telecommunications</td>
<td>voice, video, text</td>
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<tr>
<td>automotive infotronics</td>
<td>sensor data, actuator commands</td>
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<tr>
<td>home network</td>
<td>voice, music, video, data files</td>
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<tr>
<td>entertainment distribution</td>
<td>music, video</td>
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<td>telemonitoring</td>
<td>voice, video, sensor data, actuator commands</td>
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### THE "NEW AGE" OF COMPUTING:

- **mobile computing**: devices are mobile
- **pervasive computing**: devices are everywhere, embedded in the environment
- **location-aware computing**: devices know where they are and which other devices are close

Whatever it is for, ubiquitous computing needs a connection service as a subsystem.
CONNECTION SERVICES: SOME FUNCTIONS

provide interoperation between domains
find a correct endpoint for a connection
handle failure to make a connection by storing, retrying, or retargeting
handle interruption of an ongoing connection by buffering, retrying, or reconfiguring
move an endpoint of a connection without disturbing the rest of it
build a multipoint connection from point-to-point connections
bundle a set of connections
adapt or filter the signals or data transmitted through a connection

provide directory lookup
provide security
automate administration
maintain a history of network use

VERSIONS OF THESE FUNCTIONS CAN BE FOUND IN CONNECTION SERVICES FOR ALL PURPOSES

I WILL ILLUSTRATE THEM WITH TELECOMMUNICATION SERVICES (the primary purpose of which is real-time communication among people)
CONNECTION SERVICES: SOFTWARE PROBLEMS

SOME SYMPTOMS

- few well-understood requirements
- little separation of concerns between client services and resource allocation
- must be built on infrastructure that is not well-defined
- software is complex, unreliable, difficult to build, and difficult to modify
- quality of services is poor (although users may not complain, never having experienced anything better)

SOME ADDITIONAL CAUSES

- immature technology
- extremely rapid growth of networking
- extreme emphasis on performance
- IETF standards are based on "general consensus and working code", not formal specifications!
- decentralized authority
- loss of lessons learned over time

THE PRIMARY CAUSE IS THAT CONNECTION SERVICES ARE INHERENTLY DIFFICULT TO BUILD WELL

for a more specialized, but more concrete, view . . .

. . . let's look at the problem of feature modularity and feature interaction in telecommunications
## FEATURE MODULARITY

A feature is an increment of functionality with a coherent purpose.

- Voice Mail
- Do Not Disturb
- Call Waiting
- Locate Me

### FEATURES . . .

- are being added and changed continually
- can be optional for each subscriber
- can often be enabled/disabled dynamically by their subscribers

### FEATURES MUST BE MODULAR, WHICH MEANS THAT . . .

- a feature is an independent implementation unit
- a feature works correctly regardless of which other features are present/subscribed/enabled

## FEATURE INTERACTION

Features interact when one feature modifies or influences another.

### FEATURE INTERACTIONS ARE VERY COMMON

- all features are modifying or enhancing the same basic service, which is real-time communication between people
- the number of interactions is exponential in the number of features

### FEATURE INTERACTIONS CAUSE MANY PROBLEMS

- making features interact correctly is difficult
- feature interaction makes feature modularity difficult to achieve
A BAD FEATURE INTERACTION:
VOICE/PERSON CONFUSION

Alice has a personal address A with a Locate Me feature
Alice will participate in a voice conference at 2 p.m.

Alice asks to be called at A

Locate Me begins to search for Alice
"please wait while I locate Alice for you"

Locate Me plays music
the call is answered (but not by a person)

Conference Server calls A

Conference Server disconnects
"your voice conference is in progress. Please enter your PIN"
"your voice conference is in progress. Please enter your PIN"
A BAD FEATURE INTERACTION: MULTIPLE TARGET ADDRESSES

Alice calls the number of a sales group

Sales feature selects a representative on duty

Bob's cellphone is turned off

Select Representative Sales
to Sales
to Bob

call is answered by Bob's voicemail

the correct behavior is to select another sales representative

Voice Mail Bob
A BAD FEATURE INTERACTION: ABSENCE OF DUALITY

Bob@host2 wishes to be anonymous to Alice@host1

"I'm on vacation"

source = Alice@host1
target = Anon@remailer

source = Alice@host1
target = Bob@host2

contains features of Bob@host2, including an Autoresponse feature
A BAD FEATURE INTERACTION:
INCONSISTENT AVAILABILITY

if Bob dials Alice, he has Mid-Call Move, and can use it to move the conversation to his cellphone

if Bob Clicks-to-Dial Alice from a Web-based mailbox, address book, or call log, he does not have Mid-Call Move
A BAD FEATURE INTERACTION: LOST SIGNALS

VolP phone does its own tone generation

Bob's phone ignores ringback signal, because it is coming "too late" and "in the wrong direction"

Bob calls Bob, who has Add Callers

Bob attempts to add Carol to the conversation

Bob thinks Add Callers is not working, aborts the attempt to add Carol

Alice calls Bob, who has Add Callers

Bob attempts to add Carol to the conversation
THE PAST: FEATURE INTERACTION IN THE Public Switched Telephone Network (PSTN)

- In the 1960s, telephone switches became computer-controlled, making features possible.

- In the 1970s, feature interaction was recognized as a serious problem.

- Since the early 1980s, there has been extensive research on the problem, with relatively little success.

- There is widespread agreement that testing cannot solve the problem, because . . .
  - . . . there are too many cases
  - . . . testing does not predict potential interactions, distinguish good interactions from bad ones, or provide software modularity.

The effect of feature interaction on Lucent's 5ESS switch:

- Programmer productivity: 1 line of code per meeting.
- Auditing (which cleans up inconsistencies by dropping calls) is 1/3 of the code; without it, MTBF falls from 2-3 years to 2-3 hours.
THE FUTURE: FEATURE INTERACTION IN IP-BASED TELECOMMUNICATION SERVICES

- **multiple media**
  - text
  - voice
  - video

- **multiple modes**
  - real-time
  - delayed (mail)
  - conferencing

**telecommunication service**

- in any combination with

- everyone has customized, differentiated service
- people are mobile, and can be reached anywhere

- there is a variety of wired and wireless devices

- personal data is stored in the network and is accessible from anywhere

THE COMPLEXITY OF THIS VISION IS FAR BEYOND ANYTHING IN THE PSTN EXPERIENCE
GOALS OF THESE LECTURES

- to present abstractions, formal models, and analysis techniques that are relevant to connection services
- to stimulate interest in this important area of research

LIMITATIONS OF THESE LECTURES

- the focus is on services, not resources
- the focus is on networking as it should be, not on accommodating an ugly legacy
- most of this is work in progress
DISTRIBUTED FEATURE COMPOSITION (DFC) . . .

. . . IS AN ARCHITECTURE FOR SPECIFICATION AND IMPLEMENTATION OF TELECOMMUNICATION SERVICES

GOALS

- feature modularity—features are easy to add and change
- structured feature composition—feature interactions can be managed
- generality—includes mobile, multimedia, multimodal services, thus supporting all the new opportunities opened by IP
- separation from implementation concerns—can be optimized without losing integrity

HISTORY

- development of the DFC concept began in 1997
- development of the Building Box VoIP implementation of DFC began in 1999
- fundamental patent issued in 2000
- V+Plus platform, integrating Building Box with iStudio for Web services, built in 2002
- features for AT&T Consumer VoIP trial built on V+Plus in 2003
- features for AT&T CallVantage service deployed on V+Plus in 2004