Feature Interactions:
the Good, the Bad, and the Ugly

Jo Atlee • RE'11 • Trento, September 2011

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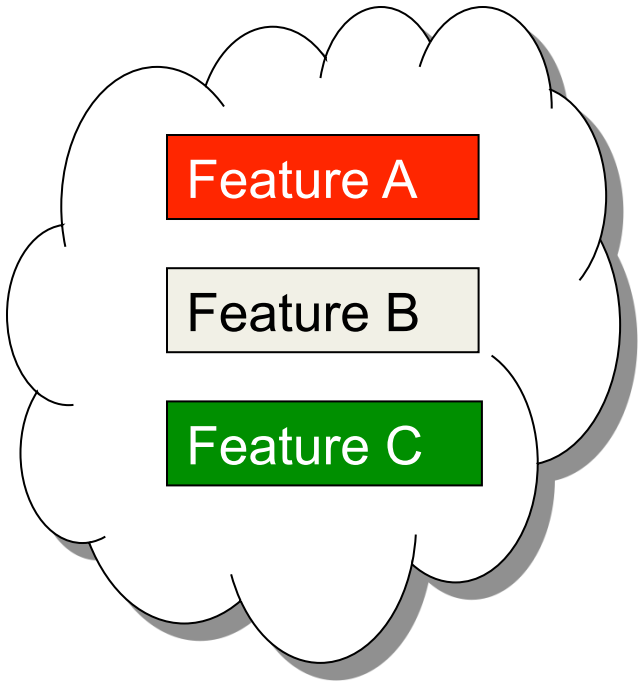
feature orientation

decomposes behaviour into feature modules

- reduces complexity
- eases evolution
- parallel feature development
- multi-vendor development

shared vocabulary



features
comparison shopping

Feature	Adobe Reader X	Acrobat X Standard	Acrobat X Pro	Acrobat X Suite
Read, print, and share PDF files				
View and print PDF files	•	•	•	•
More securely open PDF files in a sandboxed environment	•	•	•	•
Optimize your PDF viewing experience with Reading Mode	•	•	•	•
Store and share documents and forms using services at Acrobat.com[1]	•	•	•	•
Convert to PDF				
Create PDF files from any application that prints		•	•	•
Convert Microsoft Word, Excel, PowerPoint, Publisher, and Access files to PDF with one-button ease[2]		•	•	•
Scan paper documents into PDF and automatically recognize text with improved optical character recognition (OCR)		•	•	•
Capture web pages as interactive PDF files for review and archiving from Microsoft Internet Explorer and Firefox with one-button ease[2]		•	•	•
Archive emails or email folders from Microsoft Outlook or IBM® Lotus Notes with one-button ease[2]		•	•	•
Create PDF files from the clipboard, including text and images copied from external applications		•	•	•
Convert Autodesk® AutoCAD®, Microsoft Visio, and Microsoft Project files to PDF with one-button ease[2]			•	•
Export and edit PDF files				
Save PDF files as Microsoft Word documents and Excel spreadsheets, retaining the layout, fonts, formatting, and tables		•	•	•
Quickly and easily edit PDF files by making simple changes to text		•	•	•
Insert, extract, replace, delete, rotate, or reorder pages in a PDF file		•	•	•
Split large PDF files into multiple files based on maximum file size, maximum pages per file, or bookmarks		•	•	•
Add rich media to PDF files				
Insert audio, Adobe Flash® Player compatible video, and interactive media for direct playback in Acrobat and Adobe Reader®[2]			•	•
Convert a wide variety of video formats for smooth playback in PDF with Adobe Media Encoder				•
Edit and enhance photos to add to your PDF communications with Adobe Photoshop® CS5, the industry standard for image editing				•
Quickly transform static PowerPoint slides into compelling, interactive PDF presentations with Adobe Presenter				•
Rapidly combine audio, video, screen recordings, slides, and more into a rich media experience with Adobe Captivate®				•

features
configuration

Choose Your Options

Options | Standard Equipment

✕ Marked options will require changes to your current selections.

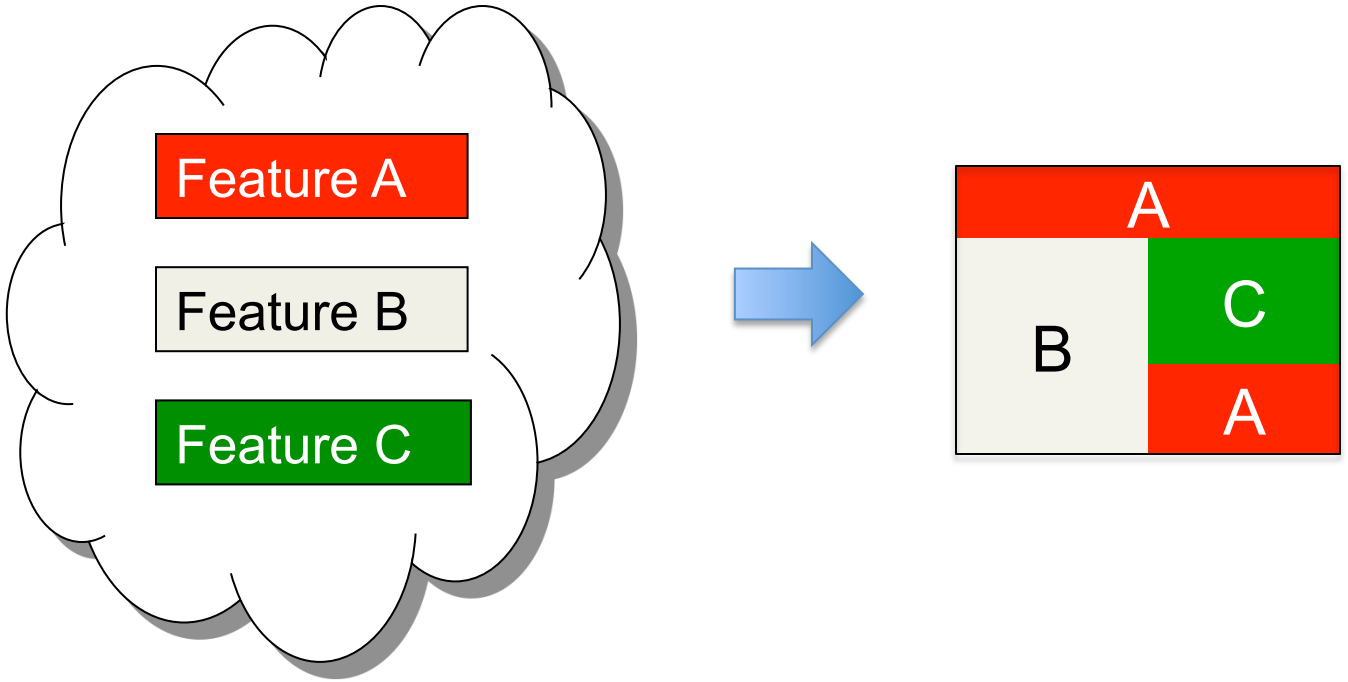
Packages	MSRP*
☐ Roof Package (Details)	$2,030
Mechanical	**MSRP***
◉ Engine: 6.2L V8 SFI	Incl.
◉ Transmission: 6 Speed Manual Short Throw (Details)	Incl.
○ Transmission: 6-Speed Paddle Shift w/Automatic (Details)	$1,565
○ Magnetic Selective Ride Control (Details)	$2,915
☐ Battery Maintainer (Details)	$115
☐ Performance Brakes (Details)	$575
Exterior	**MSRP***
◉ Tires: P245/40ZR18 Fr & P285/35ZR19 Rr (Details)	Incl.
☐ Front License Plate Mount BC/MB/NB/ON (Details)	$0
☐ Front License Plate Mt. AB/NL/NS/NT/NU/PE/QC/SK/YT (Details)	$15
☐ Cyber Gray Metallic Head Lamp Bezel	$675
☐ Blade Silver Metallic Head Lamp Bezel	$675
☐ Black Head Lamp Bezel	$675
☐ 1-Piece Removable Transparent Roof Panel (Details)	$1,095
☐ Dual Mode Performance Exhaust (Details)	$1,555
Entertainment	**MSRP***
◉ Radio: AM/FM Stereo w/CD Player & MP3 Playback (Details)	Incl.

features
third-party functionality

a classic software problem

integrate modules into a product

- such that the modules work as intended
- ***feature interaction:*** behaviour of one feature affected by the presence of another feature



interaction in automotive software

anti-theft system

- locks doors and windows
- sounds alarm if vehicle is touched

accident response system

- deploys airbags
- deactivates fuel pump
- disconnects battery from high-current devices
- unlocks door
- places call to emergency personnel

what if a thief kicks a parked car?

- in practice, nothing happens
- the interaction (like most) is resolved during development

a research community

detection, analysis, and resolution of interactions dominates the feature-development process

U.S. telecom companies galvanized researchers to work on the Feature Interaction Problem

- 1992: first workshop on feature interactions
- 1993: special issues in IEEE Computer, IEEE Communications
- 1994: benchmark of feature interactions
- 1997, 1998: feature interaction contests

what this talk is about

overview of the feature interaction problem

- characteristics of the *problem*
- manifestations of feature interactions in real-world software
- some approaches that mitigate the problem
- outstanding open problems
- especially those related to requirements engineering

some interactions in automotive software

Source of material for this section of the talk:
National Highway Traffic Safety Administration (US NHTSA)
http://www.safercar.gov

vehicle stability control

skid control features

- determine current and intended heading
- steering angle (i.e., driver's intended vehicle direction)
- vehicle's actual direction, lateral acceleration

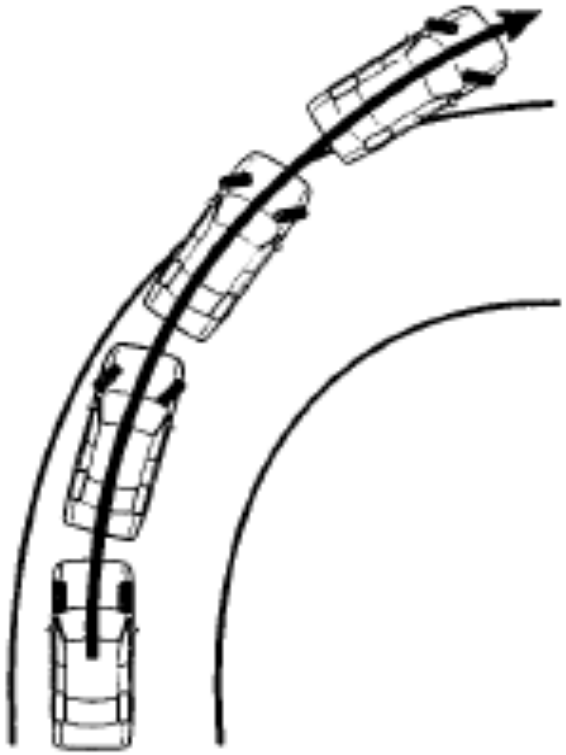
traction control features

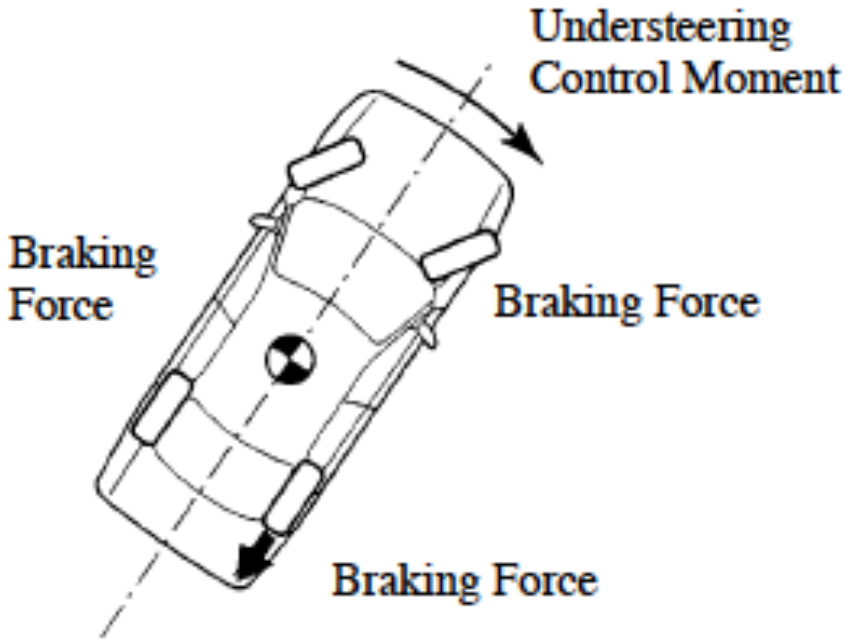
- regulate engine output and brake pressure fluid
- avoid wheel slippage
  - during starting and acceleration of vehicle
  - slippery road conditions

vehicle stability control features

- regulate engine output and brake pressure fluid
- avoid rollovers, loss-of-control situations
  - due to sudden change in road conditions
  - emergency avoidance maneuver

vehicle stability control

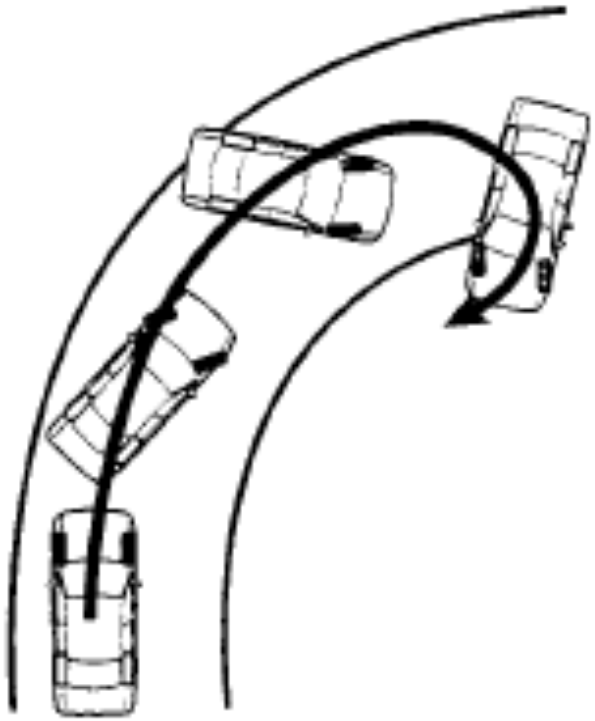


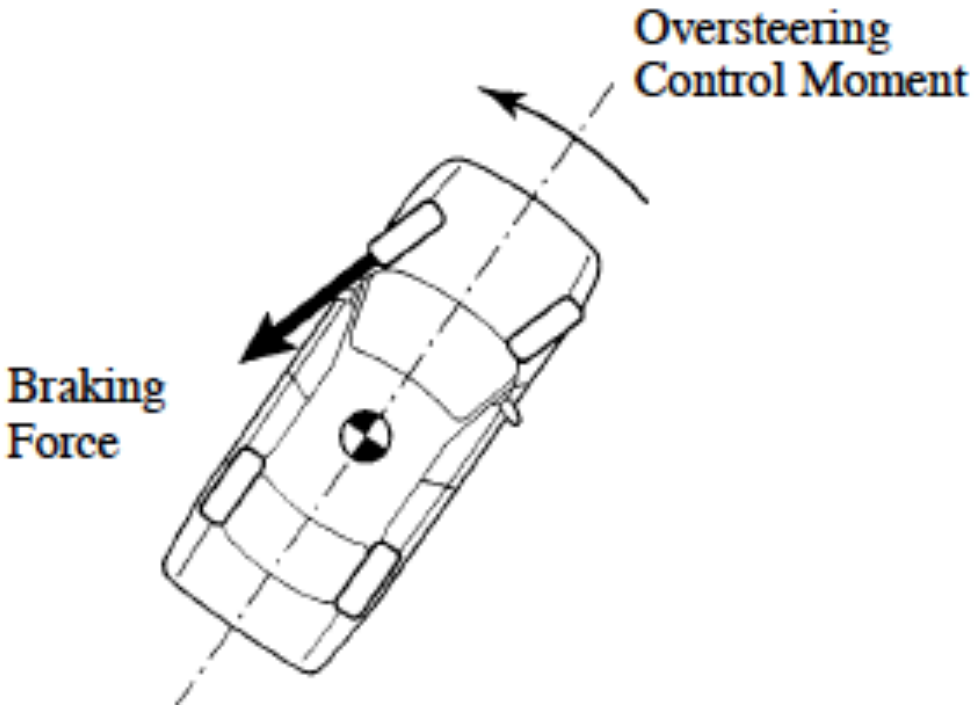


understeer:
front wheels lose grip in relation to rear wheels

dampen understeer:
- › decrease engine output
- › apply brakes to inside right rear wheel

vehicle stability control





oversteer:
rear wheels lose grip in relation to front wheels

dampen oversteer:
- › decrease engine output
- › apply brakes to outside left front wheel

steering ⊕ stability control

2003 Toyota Sequoia

skid control

- steering angle was miscalculated at low speeds
- incorrect (larger) variance between
  - driver's intended direction
  - vehicle's actual direction

inappropriate activation of traction or stability control

- driver loses throttle control
- one or more brakes may apply, slowing the vehicle
- brake lights are not illuminated
- no reported crashes, but several near misses
  - almost struck by following traffic
  - almost struck when crossing oncoming traffic

cruise control ⊕ traction control

cruise control

- vehicle set to maintain driver-specified speed

traction control

- wheels slip in rough or slippery road conditions
- engine power is increased (to maintain speed)
- driver senses “sudden acceleration”
  - vehicle becomes difficult to control

resolution:

- advise drivers not to use cruise control on slippery roads

hybrid brakes ⊕ anti-lock breaking

2010 Toyota Prius

hybrid brake system

- (normal) hydraulic brake system
- regenerative braking system
  - converts loss of vehicle momentum into electrical energy
  - stored in on-board batteries

anti-lock brake system (ABS)

- maintains stability, steerability during panic braking

interaction

- braking force after ABS actuation reduced
- on rough or slick road surfaces
- vehicle stopping distance is increased
- 62 reported crashes, 12 injuries

good interactions

not all interactions are bad!

planned interactions

- power windows ⊕ child lock
- prohibit navigation ⊕ prohibit-navigation override

unplanned but harmless interactions

- **telephony:** caller ID ⊕ call screening

(planned) resolutions to conflicts

- anti-theft system ⊕ accident response system
- (acceleration ⊕ braking) ⊕ brake override

problem: how to model planned FIs?

planned interactions are tightly coupled to their features

- feature overrides: call ID blocking, call waiting override
- conditional behaviour: active cruise control variants react to speed limit, curves, traffic, obstacles
- feature variants: 35 types of call forward in DMS 100

modelled as

- distinct features?
- fragments?
- exceptions to “normal” behaviour?
- degree of encapsulation?

good interactions gone bad

complex controllers are error-prone

- hybrid brakes ⊕ anti-lock braking

errors propagate to interacting features

- steering ⊕ stability control
- cruise control ⊕ traction control

bad interactions

violation of feature specifications

there exists an interaction if

$$F_1 \models \Phi_1$$

$$F_2 \models \Phi_2$$

$$F_1 \oplus F_2 \not\models \Phi_1 \wedge \Phi_2$$

violation of feature specifications

(Classen, Heymans, Schobblens, "What's in a Feature: A RE Perspective", FASE'08)

there exists an interaction if

$$F_1 \not\models \mathit{false}, \quad W_1 \not\models \mathit{false}, \quad \Phi_1 \not\models \mathit{false}$$

$$F_1, W_1 \not\models \mathit{false}, \quad \Phi_1, W_1 \not\models \mathit{false}, \quad F_1, W_1 \models \Phi_1$$

$$F_2 \not\models \mathit{false}, \quad W_2 \not\models \mathit{false}, \quad \Phi_2 \not\models \mathit{false}$$

$$F_2, W_2 \not\models \mathit{false}, \quad \Phi_2, W_2 \not\models \mathit{false}, \quad F_2, W_2 \models \Phi_2$$

$$\bigoplus_{i=1}^{n} F_i, \quad \bigwedge_{i=1}^{n} W_i \not\models \bigwedge_{i=1}^{n} \Phi_i$$

violation of feature specifications

there exists an interaction if

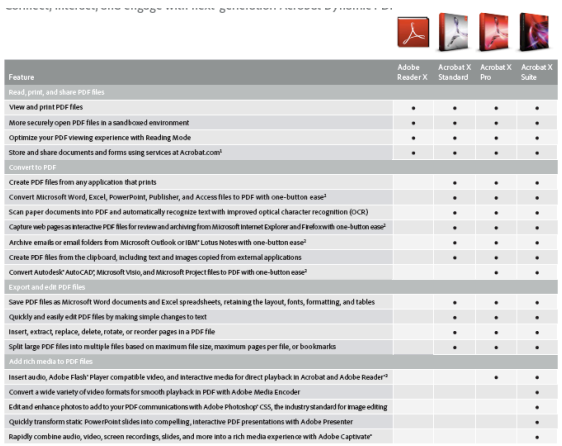
$$F_1 \models \Phi_1$$
$$F_2 \models \Phi_2$$

$$F_1 \oplus F_2 \not\models \Phi_1 \wedge \Phi_2$$

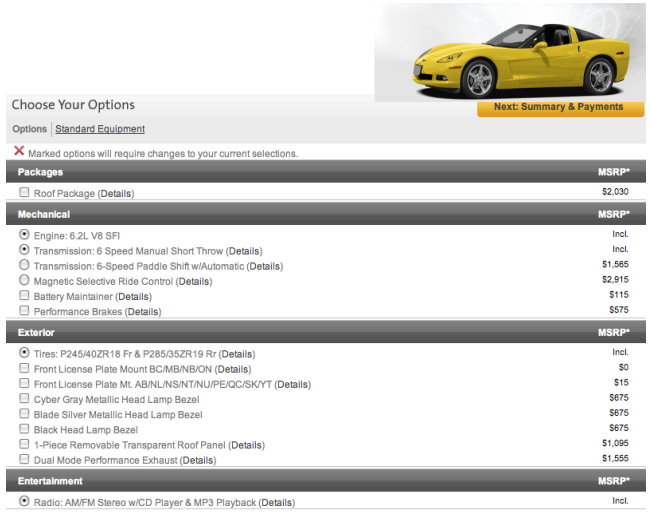
a job for formal methods!

- then what?
- what is an appropriate resolution?
- where should the fix be applied?

resolution of interactions



Feature	Adobe Reader X	Acrobat X Standard	Acrobat X Pro	Acrobat X Suite
Read, print, and share PDF files				
View and print PDF files	•	•	•	•
More securely open PDF files in a sandboxed environment	•	•	•	•
Optimize your PDF viewing experience with Reading Mode	•	•	•	•
Store and share documents and forms using services at Acrobat.com[3]	•	•	•	•
Convert to PDF				
Create PDF files from any application that prints		•	•	•
Convert Microsoft Word, Excel, PowerPoint, Publisher, and Access files to PDF with one-button ease[2]		•	•	•
Scan paper documents into PDF and automatically recognize text with improved optical character recognition (OCR)		•	•	•
Capture web pages as interactive PDF files for review and archiving from Microsoft Internet Explorer and Firefox with one-button ease[2]		•	•	•
Archive emails or email folders from Microsoft Outlook or IBM® Lotus Notes with one-button ease[2]		•	•	•
Create PDF files from the clipboard, including text and images copied from external applications		•	•	•
Convert Autodesk® AutoCAD®, Microsoft Visio, and Microsoft Project files to PDF with one-button ease[2]			•	•
Export and edit PDF files				
Save PDF files as Microsoft Word documents and Excel spreadsheets, retaining the layout, fonts, formatting, and tables		•	•	•
Quickly and easily edit PDF files by making simple changes to text		•	•	•
Insert, extract, replace, delete, rotate, or reorder pages in a PDF file		•	•	•
Split large PDF files into multiple files based on maximum file size, maximum pages per file, or bookmarks		•	•	•
Add rich media to PDF files				
Insert audio, Adobe Flash® Player compatible video, and interactive media for direct playback in Acrobat and Adobe Reader®[4]			•	•
Convert a wide variety of video formats for smooth playback in PDF with Adobe Media Encoder				•
Edit and enhance photos to add to your PDF communications with Adobe Photoshop® CS5, the industry standard for image editing				•
Quickly transform static PowerPoint slides into compelling, interactive PDF presentations with Adobe Presenter				•
Rapidly combine audio, video, screen recordings, slides, and more into a rich media experience with Adobe Captivate®				•



Choose Your Options

Next: Summary & Payments

Options | Standard Equipment

Marked options will require changes to your current selections.

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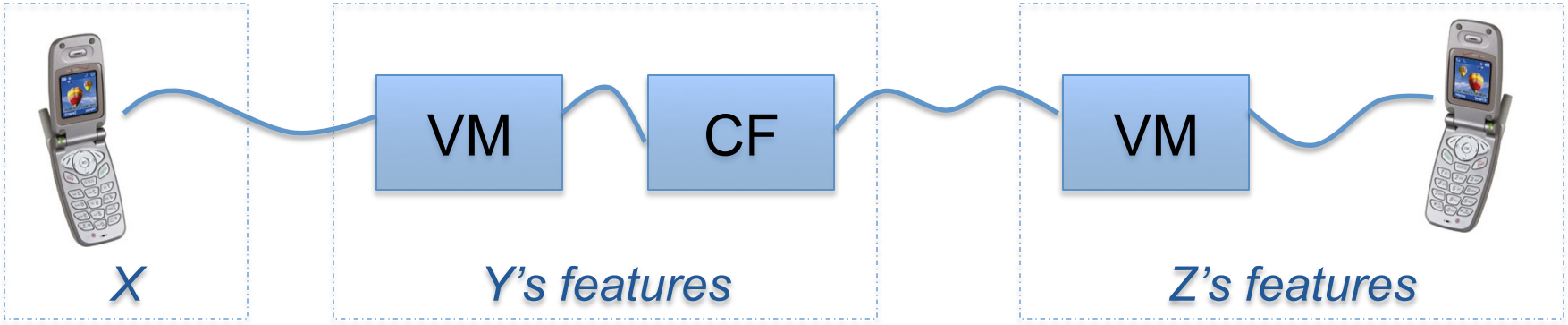
Roof Package (Details)	$2,030
Mechanical	**MSRP***
Engine: 6.2L V8 SFI	Incl.
Transmission: 6 Speed Manual Short Throw (Details)	Incl.
Transmission: 6-Speed Paddle Shift w/Automatic (Details)	$1,565
Magnetic Selective Ride Control (Details)	$2,915
Battery Maintainer (Details)	$115
Performance Brakes (Details)	$575
Exterior	**MSRP***
Tires: P245/40ZR18 Fr & P285/35ZR19 Rr (Details)	Incl.
Front License Plate Mount BC/MB/NB/ON (Details)	$0
Front License Plate Mt. AB/NL/NS/NT/NU/PE/QC/SK/YT (Details)	$15
Cyber Gray Metallic Head Lamp Bezel	$675
Blade Silver Metallic Head Lamp Bezel	$675
Black Head Lamp Bezel	$675
1-Piece Removable Transparent Roof Panel (Details)	$1,095
Dual Mode Performance Exhaust (Details)	$1,555
Entertainment	**MSRP***
Radio: AM/FM Stereo w/CD Player & MP3 Playback (Details)	Incl.

- fixed set of features
- pre-determined selection of features
- static integration
- optimal resolutions

- fixed set of features
- semi-configurable selection of features
- set of static integrations
- optimal resolutions still possible

- unlimited features
- user-defined selection of features
- dynamic integration
- optimal resolutions are not possible

best resolution not always obvious

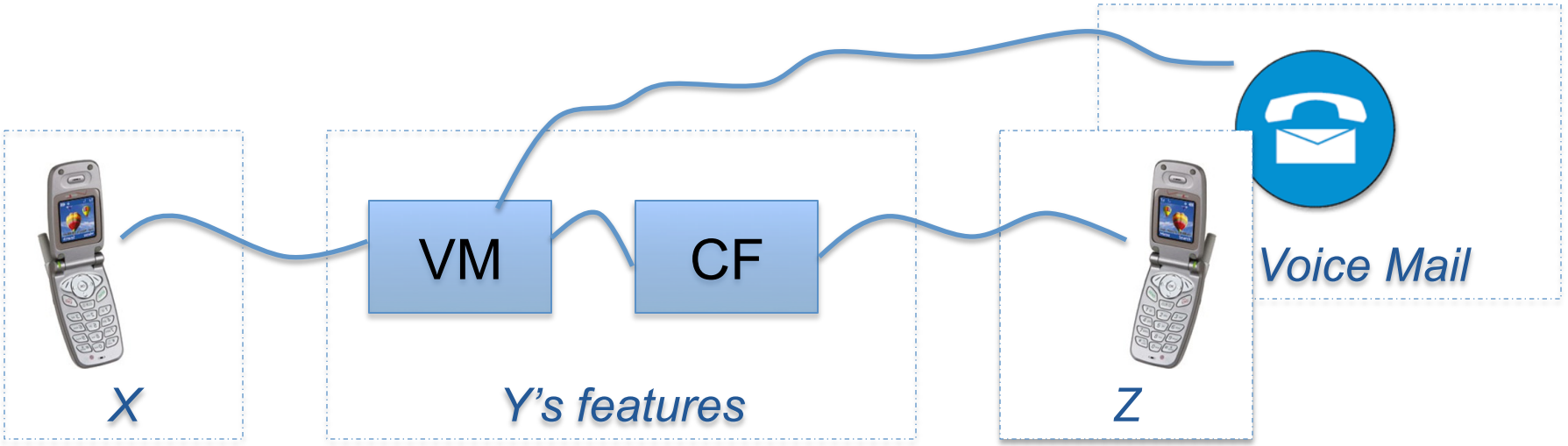


X calls Y, which forwards the call to Z, and the call attempt fails.

whose voice mail feature should react?

- what if Y is a sales group and Z is a sales representative?
- what if Y is on a long leave of absence?

interaction is not always obvious



CF $\models$ call is forwarded to new address

VM $\models$ message is from the caller is recorded

$$\text{CF} \oplus \text{VM} \overset{?}{\models} \text{forward call} \wedge \text{record message}$$

nonmonotonicity

Veldhuijsen, "Issues of non-monotonicity in feature interactin detection", FI'95

adding a new feature often requires changes to the existing system:

- nonmonotic extensions
  - e.g., freephone changes billed party
  - e.g., call screening disallows some call attempts
- violation of invariants / assumptions
  - *"I have not been able to think of a **single** interesting assertion that would be true of a system incorporating all [features of the public switched telephone network]." [Zave'01]*
- changes to definitions of terms
  - e.g., refinement of the notion of being *busy*
  - e.g., evolution of a *call*
  - e.g., evolution of directory numbers; of private numbers

correctness criteria ≠ feature req

(Zave, "Requirements for Evolving Systems: A Telecommunications Perspective", RE'01)

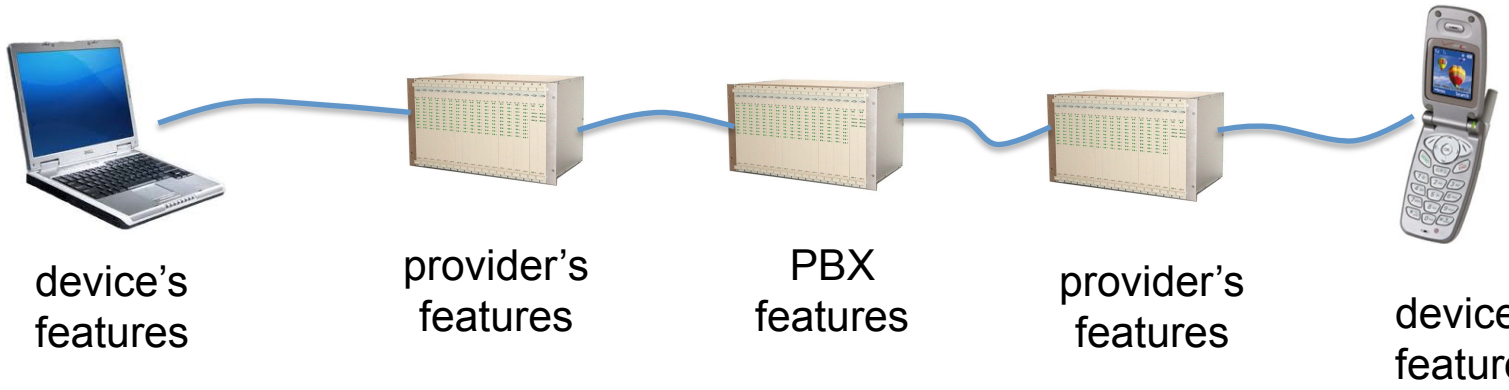
"therefore, functional verification needs as input a requirements description that states formally and explicitly exactly how all features interact.

this is exactly the chore that feature-orientation was meant to avoid!"

the ugly: scalability

lots of features

e.g., telephony has 1000+ features per system

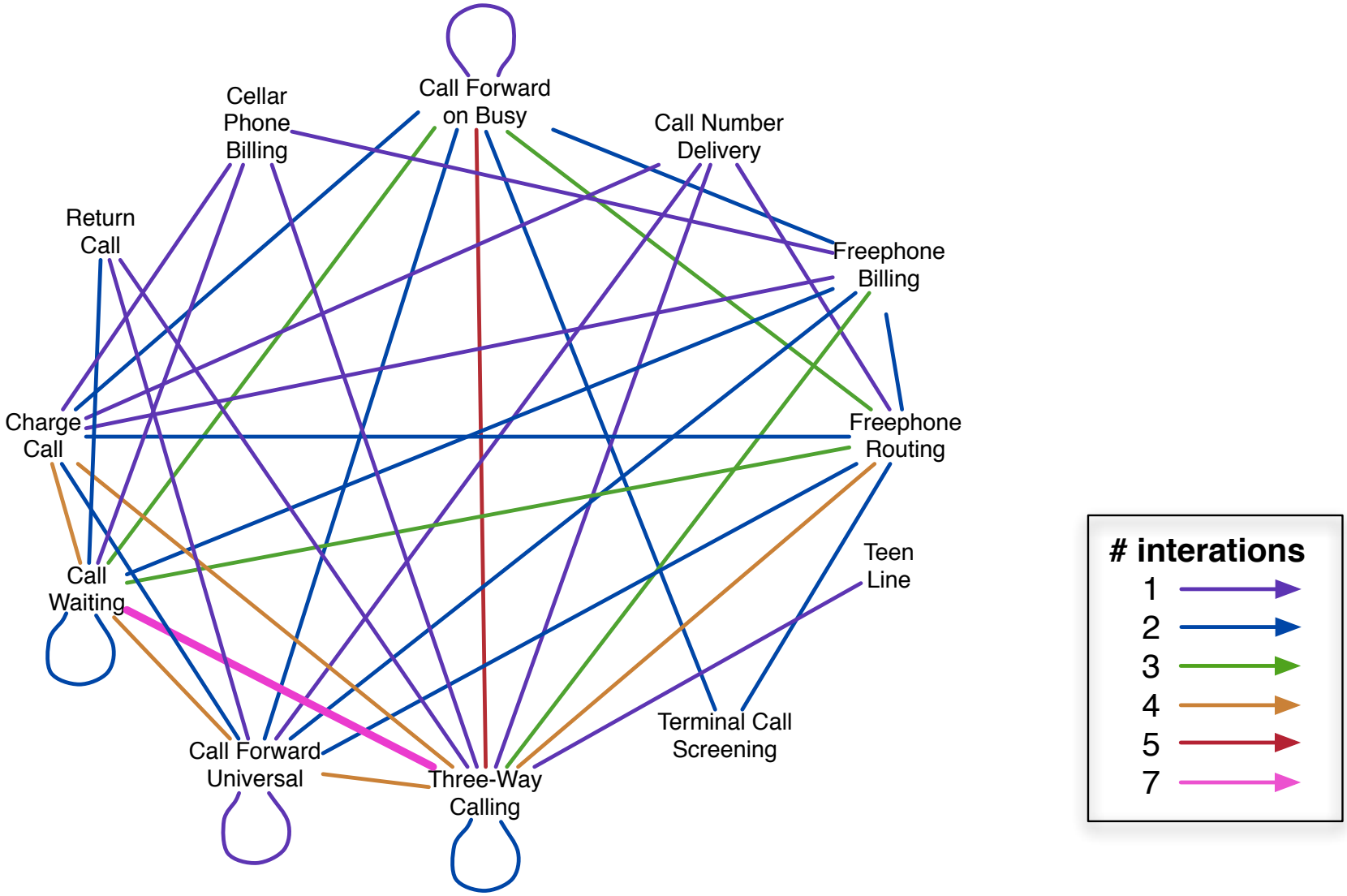


a system of feature-rich systems

- features from multiple providers
- multiple active versions of the same feature
- networked features (e.g., call waiting originating)

lots of interactions

results of the second feature interaction contest



lots of types of interactions

control-flow
one feature affects the flow of control in another feature

data-flow
one feature affects (deletes, alters) a message destined for another feature

data modification
shared data read by one feature is modified by another feature

data conflict
two features modify the same data

control conflicts
two features issue conflicting actions

assertion violation
one feature violates another feature's assertions or invariants

resource contention
the supply of resources is inadequate, given the set of competing features

lots of resolutions

death by a thousand exceptions

$$F_1 = f_1 + e_{f_2} + e_{f_3} + \ldots + e_{f_n}$$

temporal interactions

conflicting actions needn't be simultaneous

- cruise control $\oplus$ collision avoidance
- cruise control feature accelerates vehicle at time t
- collision avoidance feature brakes at time $t+\varepsilon$
- within what interval $[0..\varepsilon]$ are these actions considered in conflict?

introduced in several phases

(Bowen, "The Feature Interaction Problem in Telecommunication Systems", 1989)

[req] understanding / specifying how features ought to interact

[req] the number of interactions (and resolutions) to consider grows exponentially with the number of features

[design] more interactions introduced during design due to sharing of resources, I/O devices, protocol signals, etc.

[imp] near-commonalities among features leads to questions about how to effectively reuse software components

[test] the sheer number of interactions and resolutions to be tested lengthens the testing phase

no silver bullet

lots of features

lots of interactions

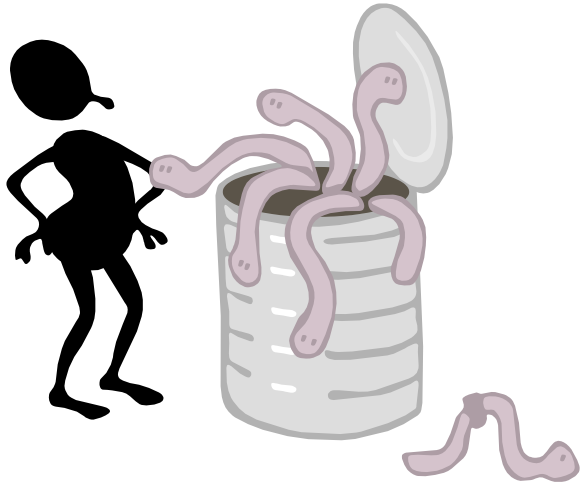
multiple types of interaction

interactions over time

introduced in several phases

lots of resolutions

not all interactions are bad



- want to confirm desired interactions and detect undesired/unexpected interactions

in search of general strategies

interaction analysis

formal methods to detect errors

- deadlock
- nondeterminism
- conflicting actions
- violations of inviolable assertions

detect interactions (potential errors)

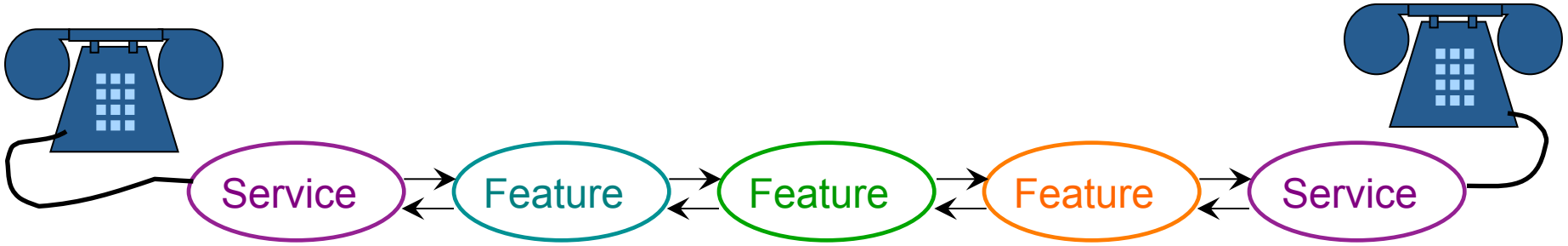
- violations of feature assumptions
- feature properties are not preserved

helpful, but not scalable

feature architectures

‘safe’ composition by design

- constrain and coordinate feature executions
- prevent entire classes of interactions



- e.g., Distributed Feature Composition [Zave, Jackson]
  - serializes features’ actions
  - feature ordering realizes a priority scheme
  - additional conventions, protocols resolve other interactions
- e.g., conflict-free composition [Hay, Atlee]

configuration analysis

reasoning about feature combinations

- explore product space

product-line model checking

- Classen et. al
- for a given property
- identifies all valid configurations of a feature set

open problem: classes of correctness criteria

- aim for safety, not absolute correctness
- aim for predictability

runtime resolution

remaining interactions must be detected and resolved at runtime

- prioritizing features
- negotiating compromises
- rollback conflicting actions
- disable feature activation
- restrict subscription to conflicting features
- terminate features; reboot

RE problems at heart

elicitation

- features, variations
- interaction resolutions
- priority schemes

analyses to

- distinguish good from bad interactions
- explore, optimize feature combinations

languages, methods to

- express partial behaviours
- feature extensions, evolutions
- support modularity
- impose resolutions

thank you

conferences

- International Conference on Feature Interactions (ICFC)
- Software Product Line Conference (SPLC)
  - http://www.splc2011.net/
- Variability Modeling of Software Intensive Systems (VaMoS)
  - http://www.**vamos-workshop.net**
- Feature-Oriented Software Development (FOSD)