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The Criticality of Systems Maintainability
and the Need for Software-Intensive System (SIS)
System Maintainability Readiness Levels

Barry Boehm, USC
PSM Users' Group Keynote
February 24, 2016

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Outline

- **Maintainability shortfalls impact all aspects of system cost-effectiveness**
  - System life-cycle cost, dependability, changeability, mission effectiveness, resilience
- **Software maintainability lags hardware maintainability in cyber-physical-human systems**
  - Systems increasingly software-intensive
  - Software maintenance differs from hardware logistics
- **Increasing costs of software maintenance and technical debt**
- **Root causes of software-intensive systems (SIS) life cycle cost escalation**
- **Addressing the root causes: SIS Maintenance Readiness Levels**
- **Conclusions**

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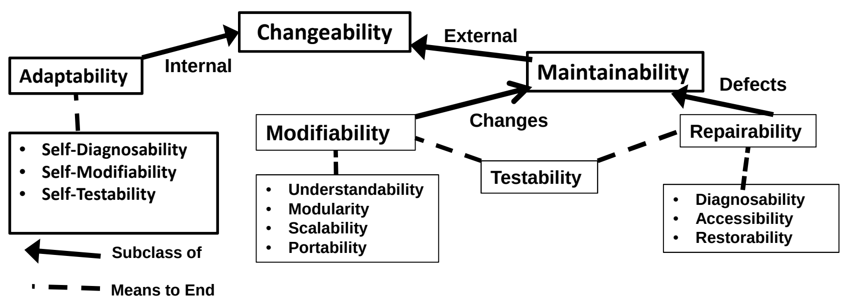
Product Quality View of Changeability

SERC SQ Ontologies: MIT Quality in Use View also valuable

- **Changeability (PQ): Ability to become different product**
  - **Swiss Army Knife Useful but not Changeable**
- **Changeability (Q in Use): Ability to accommodate changes in use**
  - **Swiss Army Knife does not change as a product but is Changeable**



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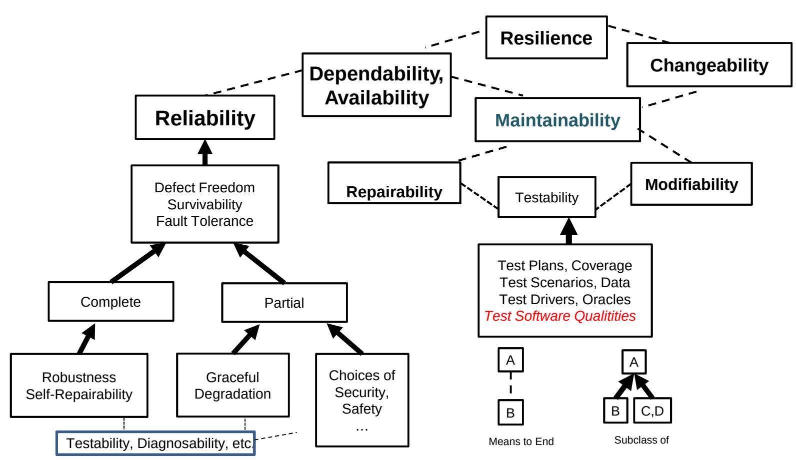
Dependability, Changeability, and Resilience



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Problem and Opportunity (%O&M costs)

- US Government IT: >73%; $58 Billion [GAO 2015]
- Cyber-Physical Systems [Redman 2008]
  - 12% -- Missiles (average)
  - 60% -- Ships (average)
  - 78% -- Aircraft (F-16)
    - 1960: 8% of functionality in software; 2000: 80% [Ferguson 2001]
  - 84% -- Ground vehicles (Bradley)
- Software [Koskinen 2010]
  - 75-90% -- Business, Command-Control
  - 50-80% -- Complex platforms as above
  - 10-30% -- Simple embedded software
- Primary current emphases minimize acquisition costs

Software Technical Debt

- Technical Debt: Delayed technical work or rework that is incurred when short-cuts are taken or short-term needs are given precedence over long-term needs
- Global Information Technology Technical Debt [Gartner 2010]
  - 2010: Over $500 Billion
  - By 2015: Over $1 Trillion
- Debt may be technical, but root causes are primarily due to foresight shortfalls in system and software processes and management

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Differences Between HW and SW Maintenance

- Software components do not degrade due to wear and fatigue;
- No imperfections or variations are introduced in making copies of software components;
  - 1 million actions to fix 1 million hardware items; only 1 for software
  - Motivates putting more functionality in software
- Software interfaces are conceptual rather than physical; there is no easy-to-visualize three-prong plug and its mate;
- There are many more distinct logic paths to check in software than in hardware;
- The failure modes are generally different. Software failures generally come with no advance warning, provide no period of graceful degredation, and more often provide no announcement of their occurrence;
- Repair of a hardware fault generally restores the system to its previous condition; repair of a software fault does not.

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Sources of Software O&M Cost Escalation

- **Software and Users evolve in Incompatible directions**
  - Non-Developmental Items (COTS, Clouds, Open Source)
  - Independently evolving co-dependent external systems
  - Multi-mission sources of change
  - Breakage of brittle point-solution architectures
  - Priority changes: competition, technology, organizations
- **Maintainers are often ill-prepared**
  - Minimal voice in acquisition
  - Missing deliverables: diagnostics, test support, architecture documentation, tool support, CM support
  - Diversity of deliverables from multiple sources
  - Unfamiliar domains, infrastructure
  - Missing capabilities: Rainy-day use cases

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Some Root Causes of O&M Cost Growth

- Stovepipe acquisition of interoperating systems
  - Incompatible infrastructure, NDIs, user interfaces, …
- Acquisitions based on lowest-cost, technically-acceptable implementation of fixed requirements, resulting in
  - Brittle, point-solution architectures
  - CAIV-driven loss of information on post-delivery needs
  - Minimal interpretation of “technically acceptable”
    - Just implementing sunny-day requirements
- Minimal maintainer participation, planning, preparation
  - Missing maintainer deliverables: diagnostics, test support, architecture documentation, tool support, CM support
  - Incompatibilities among post-deployment evolution parties
- Inadequate SysE resources, leading to severe technical debt
  - First to be impacted by optimistic budgets and schedules

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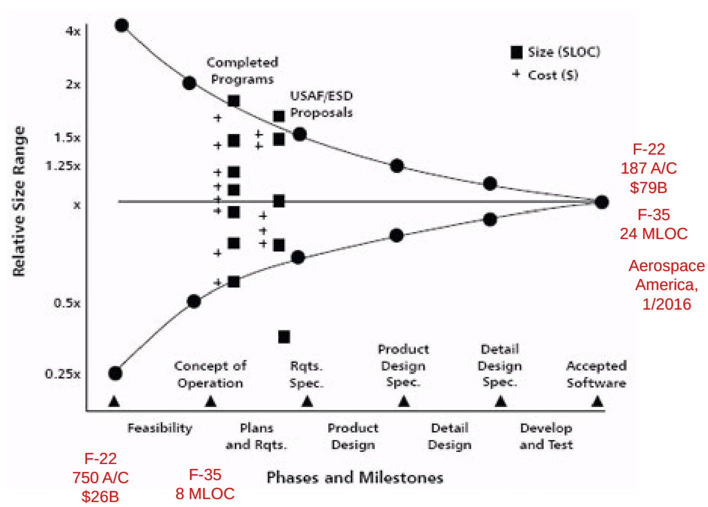
The Conspiracy of Optimism

Take the lower branch of the Cone of Uncertainty



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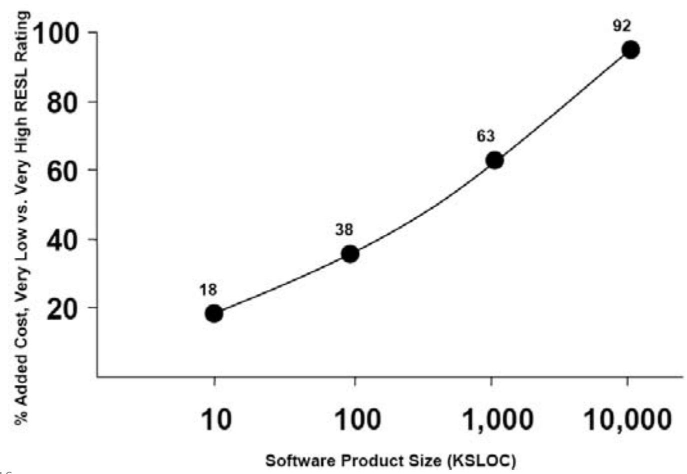
Added Cost of Minimal Software SysE

Based on COCOMO II calibration data



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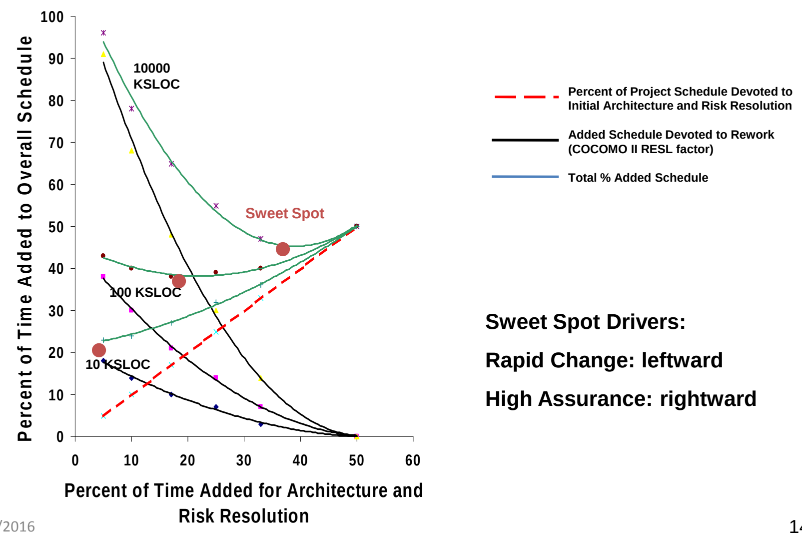
How Much Architecting is Enough?



Sweet Spot Drivers:

Rapid Change: leftward

High Assurance: rightward

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Opportunities to Reduce Maintenance Costs

- Many opportunities to reduce total ownership costs (TOC)
  - By emphasizing software Changeability and Dependability
  - Both rely on Maintainability via SERC System Qualities Ontology
- Opportunities organized via Maintainability Opportunity Trees
  - Anticipate Modifiability Needs
  - Design, Develop for Modifiability
  - Anticipate Repairability Needs
  - Design, Develop for Repairability
  - Expedite Diagnosis
  - Improve Modification and Repair Verifiability; Skills

Maintainability Opportunity Tree: Modifiability

- Anticipate Modifiability Needs
  - Evolution information
  - Trend analysis
  - Hotspot (change source) analysis
  - Modifier involvement
  - Address Potential Conflicts
- Design/Develop for Modifiability
  - Modularize around hotspots
  - Service-orientation; loose coupling
  - Spare capacity; product line engineering
  - Domain-specific architecture in domain
  - Enable user programmability
  - Address Potential Conflicts
- Improve Modification V&V
  - Prioritize, Schedule Modifications, V&V
  - Modification compatibility analysis
  - Regression test capabilities
  - Address Potential Conflicts

Maintainability Opportunity Tree: Repairability

- Anticipate Repairability Needs
  - Repair facility requirements
  - Repair-type trend analysis
  - Repair skills analysis
  - Repair personnel involvement
  - Address Potential Conflicts
- Design/Develop for Repairability
  - Repair facility design, development
  - Replacement parts trend analysis
  - Replacement parts logistics development
  - Replacement accessibility design
  - Address Potential Conflicts
- Improve Repair Diagnosis
  - Smart system anomaly, trend analysis
  - Informative error messages
  - Multimedia diagnosis guides
  - Fault localization
  - Switchable spare components
  - Address Potential Conflicts
- Improve Repair, V&V Processes
  - Prioritize, Schedule Repairs, V&V
  - Repair compatibility analysis
  - Regression test capabilities
  - Address Potential Conflicts

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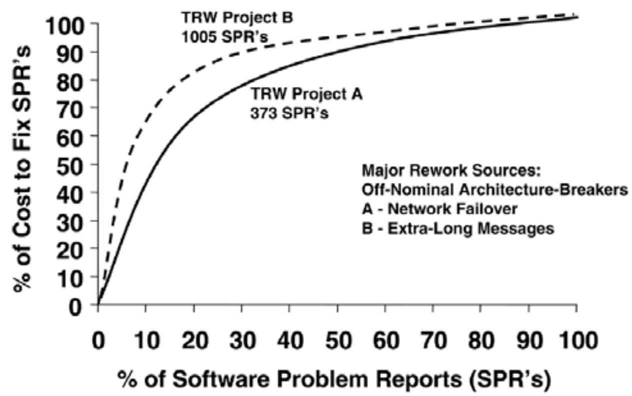
Elaborating Modifiability Benefits - I

- **Evolution Information**
  - Keep, prioritize below-the-line IOC desired capabilities
  - Use to determine modularization around sources of change, reduce ripple effects of changes
- **Trend Analysis**
  - Identify, prioritize responses to sources of change
    - Marketplace, competition, usage trends, mobility trends
  - Use to refine, evolve architecture
- **Agile Methods, User Programmability**
  - Enable rapid response to rapid change
- **Hotspot Analysis**
  - Gather data on most common sources of change
  - Use to modularize architecture, reduce ripple effects of changes

Use of Empirical Data in TOC Models: Pareto 80-20 Cost-to-fix Distribution

Contracts: Fixed cost and nominal-case requirements; 90 days to PDR



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Rework Sources Analysis: Projects A and B

- Change processing over 1 person-month = 152 person-hours

Category	Project A	Project B
Extra long messages		3404+626+443+328+244= 5045
Network failover	2050+470+360+160= 3040	
Hardware-software interface	620+200= 820	1629+513+289+232+166= 2832
Encryption algorithms		1247+368= 1615
Subcontractor interface	1100+760+200= 2060	
GUI revision	980+730+420+240+180 =2550	
Data compression algorithm		910
External applications interface	770+330+200+160= 1460	
COTS upgrades	540+380+190= 1110	741+302+221+197= 1461
Database restructure	690+480+310+210+170= 1860	
Routing algorithms		494+198= 692
Diagnostic aids	360	477+318+184= 979
TOTAL:	**13620**	**13531**

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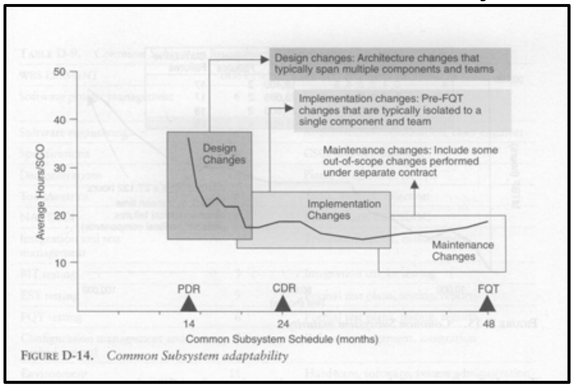
C4ISR Project C: Architecting for Change

USAF/ESC-TRW CCPDS-R Project*

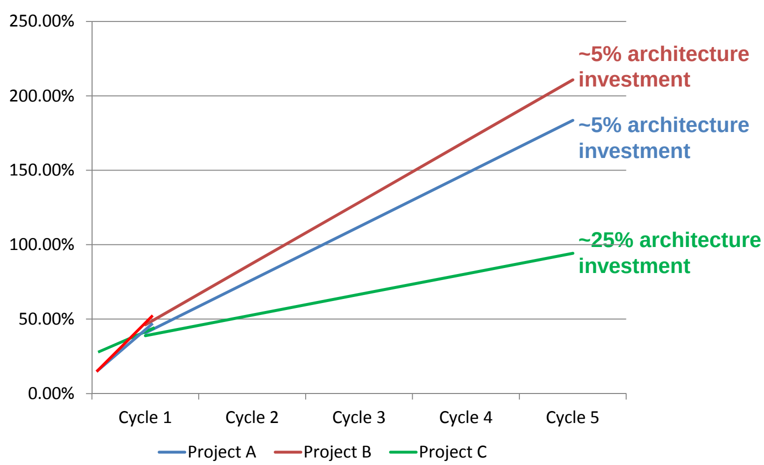


When investments made in architecture, average time for change order becomes relatively stable over time…

* Walker Royce, *Software Project Management: A Unified Framework*. Addison-Wesley, 1998.

Relative* Total Ownership Cost (TOC)

For single system life cycle (TOC-SS)



* Cumulative architecting and rework effort relative to initial development effort

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Elaborating Modifiability Benefits – II
and Repairability Benefits

- Service-Oriented Architecture improves Interoperability
- Product-Line Engineering improves Total Ownership Cost (TOC)
  - Identify, modularize around product line Commonalities
  - Develop domain architecture, interfaces to Variabilities
  - Fewer components to modify, repair
- Improved Repairability improves Availability, TOC
  - Availability = MTBF / (MTBF + MTTR)
- Stakeholder Value-Based V&V improves Cost, Mission Effectiveness
  - Prioritizing inspection, test activities
  - Balancing level of inspection, test activities vs. rapid fielding

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Cost of Downtime Survey

- *Industry Sector Revenue/Hour*
- Energy $2.8 million
- Telecommunications $2.0 million
- Manufacturing $1.6 million
- Financial Institutions $1.4 million
- Information Technology $1.3 million
- Insurance $1.2 million
- Retail $1.1 million
- Pharmaceuticals $1.0 million
- Banking $996,000
- *Source: IT Performance Engineering & Measurement Strategies: Quantifying Performance Loss, Meta Group, October 2000.*

Addressing Potential Conflicts

- **With Performance: Loose vs. tight coupling (supercomputing)**
- **With Development Cost and Schedule: More to design, develop, V&V (rapid fielding)**
- **With Usability: Too many options (Office 2010)**
- **With Security: Too many entry points (Windows)**
- **With Scalability, Safety, Security: Agile methods**
- **With Dependability: User Programming, Self-Adaptiveness**
- **With Interoperability: Multi-Domain Architectures**
- **With Cost, Resource Consumption: Spare Capacity**

These are not always conflicts, but candidates to consider. Need to balance risk of too little Modifiability with risk of too much.

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SIS Maintainability Readiness Levels

Software-Intensive Systems Maintainability Readiness Levels			
SMR Level	**OpCon, Contracting: Missions, Scenarios, Resources, Incentives**	**Personnel Capabilities and Participation**	**Enabling Methods, Processes, and Tools (MPTs)**
9	5 years of successful maintenance operations,including outcome-based incentives, adaptation to new technologies, missions, and stakeholders	In addition, creating incentives for continuing effective maintainability. performance on long-duration projects	Evidence of improvements in innovative O&M MPTs based on ongoing O&M experience
8	One year of successful maintenance operations, including outcome-based incentives, refinements of OpCon.	Stimulating and applying People CMM Level 5 maintainability practices in continuous improvement and innovation in such technology areas as smart systems, use of multicore processors, and 3-D printing	Evidence of MPT improvements based on ongoing refinement, and extensions of ongoing evaluation, initial O&M MPTs.
7	System passes Maintainability Readiness Review with evidence of viable OpCon, Contracting, Logistics, Resources, Incentives, personnel capabilities, enabling MPTs	Achieving advanced People CMM Level 4 maintainability capabilities such as empowered work groups, mentoring, quantitative performance management and competency-based assets, particularly across key domains.	Advanced, integrated, tested, and exercised full-LC MBS&SE MPTs and Maintainability-other-SQ tradespace analysis
6	Mostly-elaborated maintainability OpCon. with roles, responsibilities, workflows, logistics management plans with budgets, schedules, resources, staffing, infrastructure and enabling MPT choices, V&V and review procedures.	Achieving basic People CMM levels 2 and 3 maintainability practices such as maintainability work environment, competency and career development, and performance management especially in such key areas such as V&V, identification & reduction of technical debt.	Advanced, integrated, tested full-LC Model-Based Software & Systems (MBS&SE) MPTs and Maintainability-other-SQ tradespace analysis tools identified for use, and being individually used and integrated.
5	Convergence, involvement of main maintainability success-critical stakeholders. Some maintainability use cases defined. Rough maintainability OpCon, other success-critical stakeholders, staffing, resource estimates. Preparation for NDI and outsource selections.	In addition, independent maintainability experts participate in project evidence-based decision reviews, identify potential maintainability conflicts with other SQs	Advanced full-lifecycle (full-LC) O&M MPTs and SW/SE MPTs identified for use. Basic MPTs for tradespace analysis among maintainability & other SQs, including TCO being used.
4	Artifacts focused on missions. Primary maintenance options determined, Early involvement of maintainability success-critical stakeholders in elaborating and evaluating maintenance options.	Critical mass of maintainability SysEs with mission SysE capability, coverage of full M-SysE.skills areas, representation of maintainability success-critical-stakeholder organizations.	Advanced O&M MPT capabilities identified for use: Model-Based SW/SE, TCO analysis support. Basic O&M MPT capabilities for modification, repair and V&V: some initial use.
3	Elaboration of mission OpCon, Arch views, lifecycle cost estimation. Key mission, O&M, success-critical stakeholders (SCSHs) identified, some maintainability options explored.	O&M success-critical stakeholders's provide critical mass of maintainability-capable Sys. engrs. Identification of additional. M-critical success-critical stakeholders.	Basic O&M MPT capabilities identified for use, particularly for OpCon, Arch, and Total cost of ownership (TCO) analysis: some initial use.
2	Mission evolution directions and maintainability implications explored. Some mission use cases defined, some O&M options explored.	Highly maintainability-capable SysEs included in Early SysE team.	Initial exploration of O&M MPT options
1	Focus on mission opportunities, needs. Maintainability not yet considered	Awareness of needs for early expertise for maintainability. concurrent engr'g, O&M integration, Life Cycle cost estimation	Focus on O&M MPT options considered

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SIS Maintainability Readiness Levels 1-3

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SIS Maintainability Readiness Levels 3-5

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SIS Maintainability Readiness Levels 5-7

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SIS Maintainability Readiness Levels 7-9

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SMRL Usage vs. Complexity, Criticality, Continuity

SMRL Level Vs. DoD Milestone	Simple, Non-Critical, Organic	Simple, Non-Critical, Transitioned	Intermediate	Highly Complex, Critical
MDD	1	1	2-3	3
MS A	2	3	4-5	5
MS B	3	4	6	6
IOC	5	6	7	7

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- **Root causes explain sources of software-intensive systems (SIS) life cycle cost escalation**
- **SIS Maintenance Readiness Levels framework enables projects to confront and overcome the root causes**

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