How to select your RTOS?

Bits&Chips Micro-event: Embedded Operating Systems

Jan 29th 2004

Ger Schoeber

TASK SWITCH

Overview

- Resumé of the speaker
- Operating System
- Real-Time
- A use case
- The selection method explained
  - Application areas & characteristics
  - RTOS characteristics
  - “musts & wants”, weighing factors (Kepner Tregoe)
  - Devils advocate
- Is there a new future for the method?

Ger Schoeber

- 1984 Philips I&E
- 1989 High Tech Automation (since 2000: Ordina TA)
- 2001

1984 – 1989: Philips I&E

Distributed
Real-time
Mulitprocessor
Operating **System**

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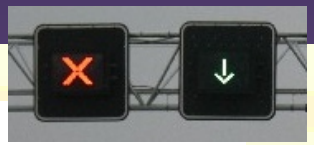
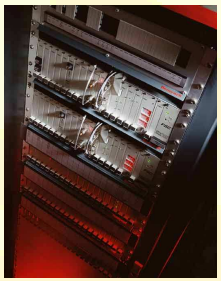
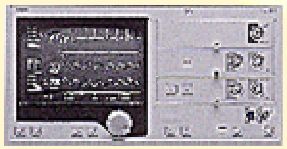
TASK SWITCH

1989 – 2001: High Tech Automation

- Philips Telecom & Data Systems
- Océ Research & Technology
- Pepperl & Fuchs (currently Honeywell)
- Dräger Medical Electronics
- Alcatel
- Vanderlande Industries
- High Tech Automation
- Philips Semiconductors







Philips Medical Systems
Philips Semiconductors
Siemens VDO Car Systems
FEI Electron Optics
Océ Technologies
Stork PMT
Heidelberg Contiweb
Philips ED&T
Philips CE CDS
Philips IA (Jabil)

2001 – today: Task Switch

Hogeschool van Utrecht	*Guest lectures*
Philips DN Softworks	*Mgt support / Prj control*
Philips Centre for Technical Training	*Lecturer System Architecting*
Ordina Technical Automation	*Coaching Architect*
Philips Digital Systems Lab	*Project Evaluation Workshops*
ALVA Nederland BV	*Project Evaluation / Improvement Workshop*
Philips Semiconductors BL-Storage	*Mgt supp / SA supp / Prj control*
Dräger Medical	*Coaching Architect*
PT Embedded, Computable, LAC, Bits&Chips	*Articles, Presentations*
Philips Semiconductors ICE	*Management Presentation*

Task Switch

Services:

- Personal Coaching (*Architects*, Managers, Engineers)
- Evaluation and Improvement Workshops
- System / Software Architect -interim
- Project Management -interim

Market:

- Technical Automation, Embedded Systems

Why using an OS?

- Interface: application ↔ hardware
- Offering services to the application(s)

Hardware abstraction

- File and device I/O
- Communication and network I/O
- Hardware control, graphics

Services

- Scheduling
- Communication
- Synchronisation

What makes an OS Real-Time?

- Deterministic
- Guaranteed worst case interrupt latency
- Guaranteed worst case context switch time
- Hard / firm / soft real-time:
  catastrophic / quality reduction / acceptable

Deterministic

The worst-case **execution time** of each of the system calls is **calculable**.

Needs:

- Mininum, average, maximum number of **clock cycles** required by each system call.

Numbers might differ per **processor type**.

*Worst case performance of the application software can be analysed using Rate Monotonic Analysis (**RMA**).*

Rate Monotonic Scheduling

- Assign the priority of each task according to its period:
  the **shorter** the period the **higher** the priority.
- Works for **fixed-priority** pre-emptive RTOS.
- The worst-case schedulable bound is about **69.3 %** (= ln 2). *(Wn = n * (2^(1/n) - 1))*
- Maximum utilisation is reached when all tasks are **harmonic**.

Interrupt latency

From **interrupt** arriving at the processor until the **start** of the associoated interrupt service **routine** (ISR).

- Processor must **finish** executing the current instruction.
- The interrupt **type** must be recognised (hardware).
- The CPU's **context** must be saved.
- The **ISR** associated with the interrupt is started.
- If interrupts are **disabled** (e.g. during a system call), the worst-case interrupt latency increases by the maximum amount of time that they are turned off.

Context switch

From **suspending** one process from execution by the CPU until another process is **started**.

- The context of the process must be **saved**.
- The process **administration** within the kernel is updated (***scheduling***).
- Possibly control MMU (hardware).
- The context of the next process must be **loaded**.

A use case 1/2

Context:
- Consumer product
- Multi-processor architecture
- High volume
- Low BOM
- Short market introduction window
- Contains pSOS+

Issue:
pSOS+ end of life

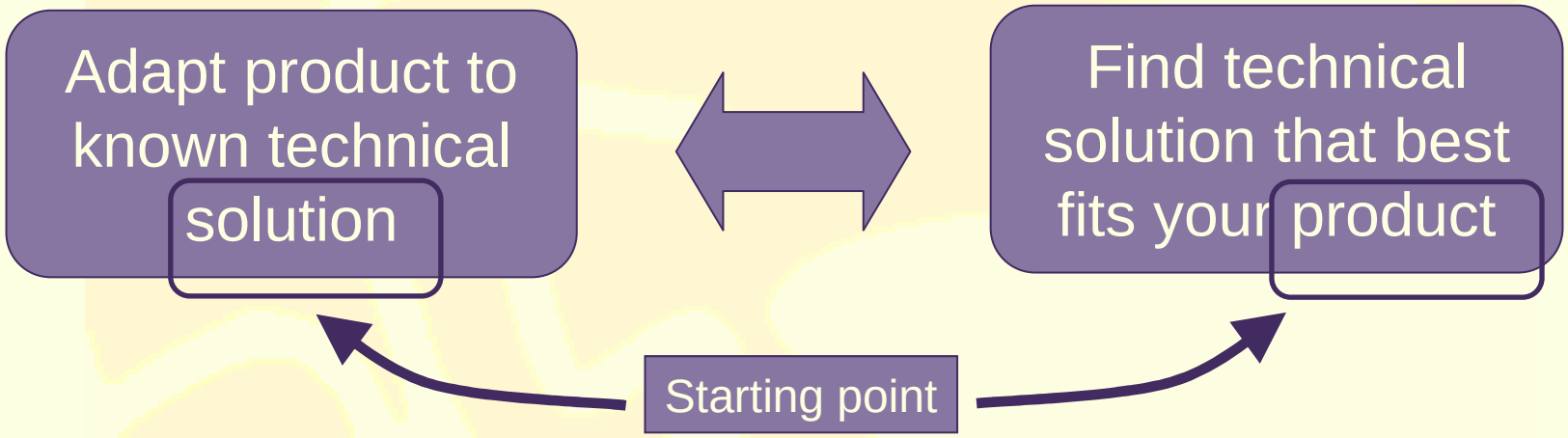
Fact:
- pSOS+: ISI→
- WindRiver support
- → Boldly go for VxWo

Other OS's in the market?
- Which?
- Characteristics:
  - Leaflets / sales
  - Benchmarking
    - Technical
    - Usage/introduction
    - Costs (development seat, run-time licenses)
- Fit for purpose:
  - Now (short term)
  - Future (long term)

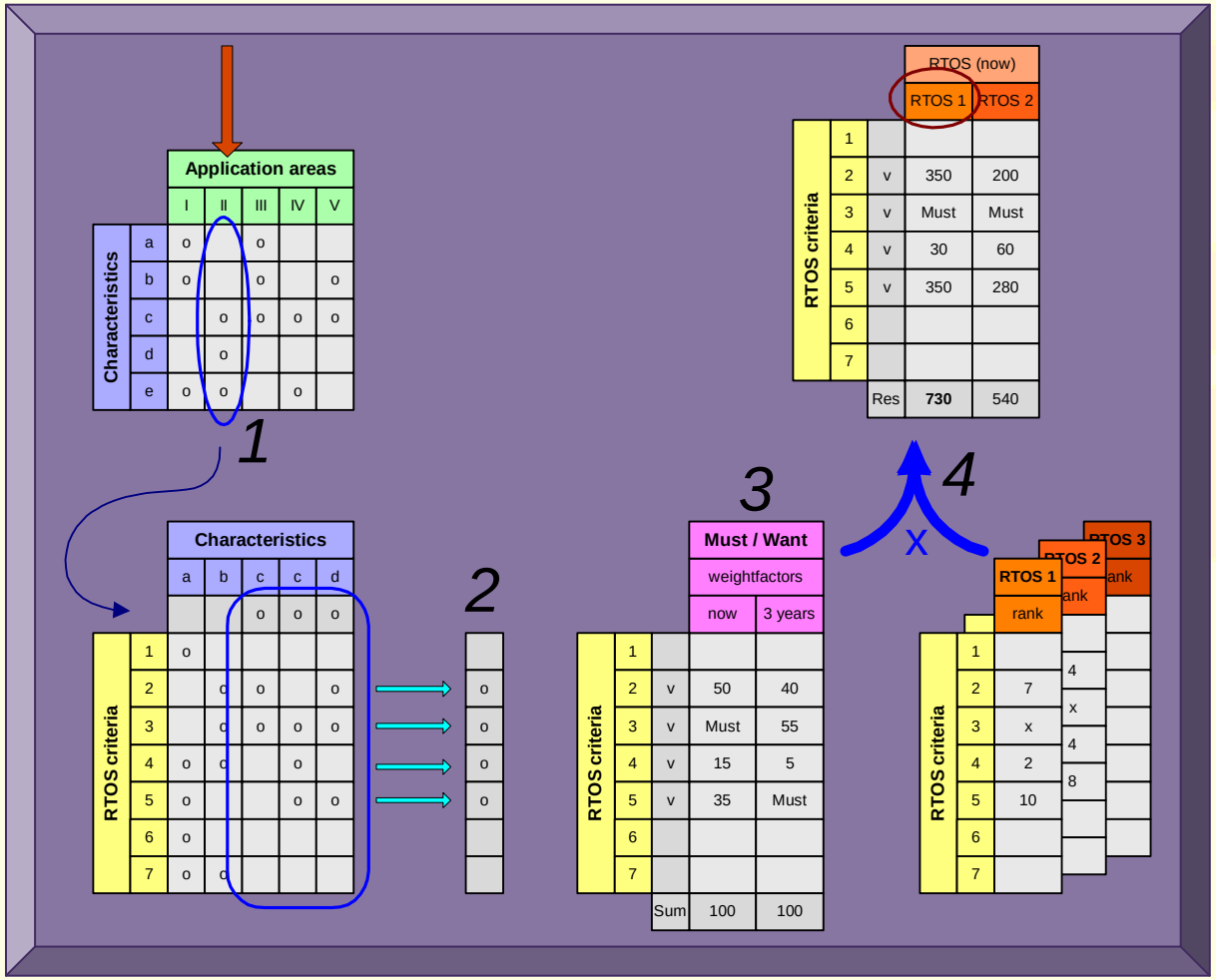
Analysis: Δ pSOS+ / VxWorks?
- SDE
- HW support
- Licences
- API – syntax/semantics
- Footprint
- Performance

A use case 2/2

Technology versus Requirements driven:



RTOS selection method



A method that starts from the application point of view

History, evolution and future (?) of the selection method

High Tech Automation (Ordina TA): 1993-1994

- Organisations struggle finding the right RTOS
- Started a study comparing characteristics of available RTOS
- Results presented to large group of organisation representatives

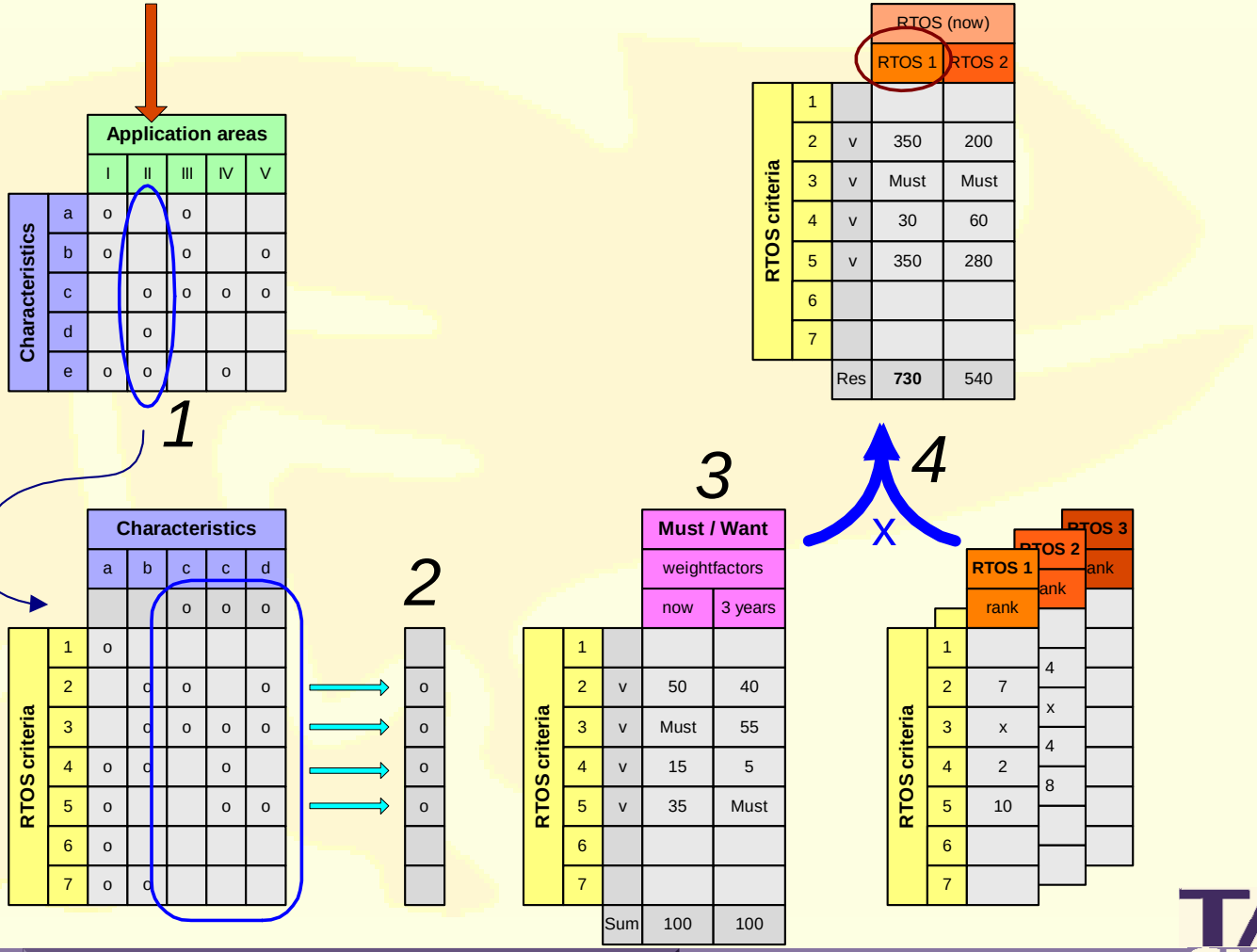
Philips CFT + High Tech Automation: 1995-1997

- Initiative to develop a selection method based on Kepner Tregoe
- Additional effort in benchmarking RTOSes
- 2 Reports available on the method & evaluated RTOSes

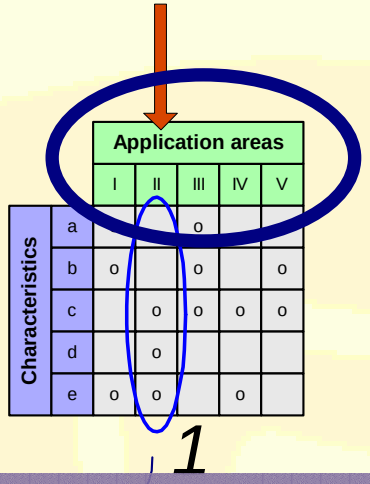
Task Switch: 2004

- Ideas to update method data + benchmarking courant RTOSes
- Ordina TA showed interest
- **Others ? → ger.schoeber@task-switch.nl**

The complete method



Application areas



Consumer products:










Professional systems:

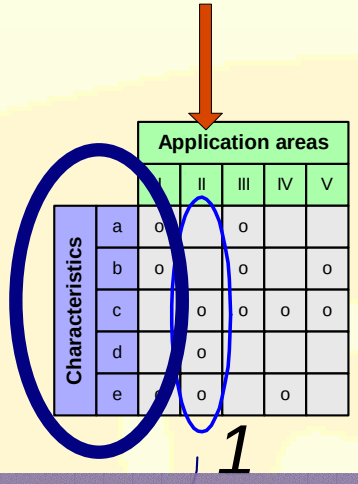








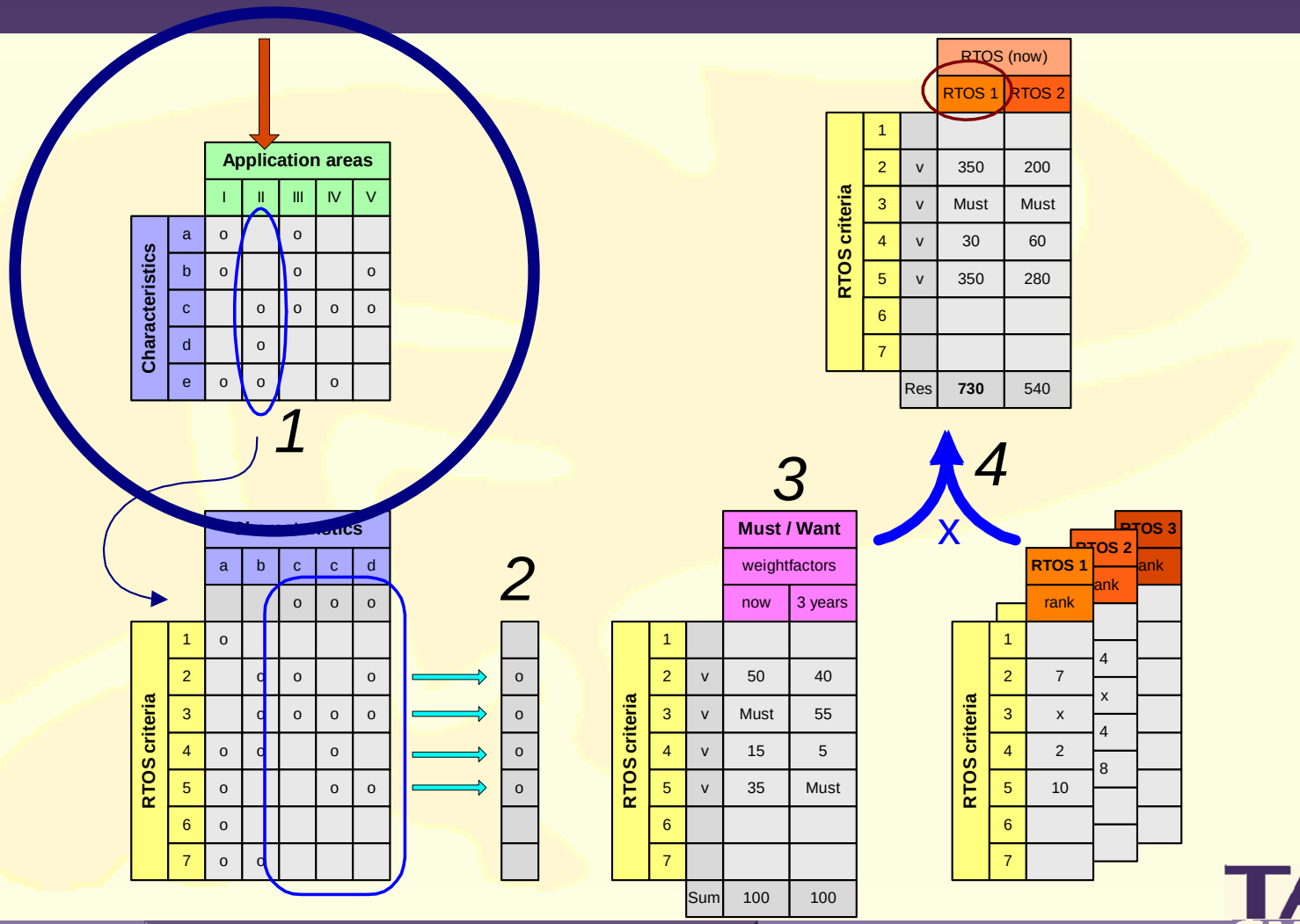
Application characteristics



Monitoring
Device interfacing
Data acquisition
Signal processing
Level of robustness

Quantity
Development costs
Product price
Upgradability
Life span
Level of optimisation
Successive generations
Level of standardisation
Hard real-time constraints
Data communication
Control
Database

Application areas x Application characteristics



Application areas x Application characteristics

Consumer Products

LEGEND				
	+++	*very important*	↑↑	*strong positive trend*
	---	*very unimportant*	↓↓	*strong negative trend*
	o	*none*	~	*stable*

Area	Consumer products									
Characteristics	Telephony		Audio/Video		Domestic appliances		Automotive		Multimedia	
Quantity	++	↑	++	↓	++	↑	++	↑	-	↑↑
Development costs	+++	↑	++	↓	++	↑↑	++	↑	+++	↑
Product price	+	↑↑	++	↑	+	~	+	~	o	~
Upgradability	--	~	-	↑	--	~	--	↑	+	↑
Life span	--	↓	--	↓	-	↓	--	~	-	↓
Level of optimisation	+++	↓	+++	↓	+++	↓	++	↓	o	~
Succesive generations	+	↑	++	↑	o	~	o	↑	+	↑↑
Level of standardisation	++	↑	++	↑	-	↑	+	↑	+	↑↑
User interfacing	+	↑	++	↑	+	↑	o	↑	+	↑↑
Real-time response time (μs)	1000	↑	2000	↑	1000	↑	10	↑	100	↑
Level of concurrency	-	↑	-	↑	-	↑	-	↑	+	↑↑
Hard real-time constraints	-	~	-	~	-	~	++	↑↑	+	↑
Data communication	+	~	o	↑	o	~	o	↑	+	↑↑
Control	-	~	-	~	o	↑	+	↑	-	~
Monitoring	-	~	-	~	+	~	+	↑	-	~
Device interfacing	-	~	-	~	-	~	+	↑	+	↑
Data acquisition, signal processing	+	↑	+	~	-	↑	+	↑	+	↑
Level of robustness	-	~	-	~	--	~	++	~	-	~
Database	-	~	-	~	--	~	+	~	+	↑

Application areas x Application characteristics

Professional Products

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	+++	*very important*	↑↑	*strong positive trend*
	---	*very unimportant*	↓↓	*strong negative trend*
	o	*none*	~	*stable*

Area	Professional products																					
Characteristics	Security systems		Military equipment		Production equipment		Process industry		Medical equipment		Laboratory equipment		Transport sector		Communications		Simulations		Data acquisition	
Quantity	+	↑	-	↑	o	↑	o	↑	-	~	--	~	++	↑	-	↑↑	--	↑	o	↑
Development costs	o	↑	++	~	+	↑	o	↑	+	↑↑	-	↑	+	~	++	↑	+++	↑	+	↑
Product price	-	~	---	↑	+	~	++	~	+++	↑	o	~	+	~	o	~	+++	~	+	↑
Upgradability	++	~	o	~	++	↑	+	↑	+	↑	+++	~	o	↑	++	↑	+	~	o	↑
Life span	++	↑	++	~	++	~	++	~	+	↓	+	~	+	↓	++	~	++	~	+	~
Level of optimisation	-	~	---	~	--	~	-	~	--	~	---	~	o	~	--	~	-	~	+	~
Succesive generations	--	↑	---	~	+	~	---	~	+	↑	--	~	--	↑	--	↑	--	~	-	~
Level of standardisation	--	↑	---	~	+	↑	++	↑	-	↑↑	--	~	+	↑	++	↑	-	↑	-	↑
User interfacing	--	↑	-	↑	+	↑	+	↑	o	↑	o	↑	-	↑	-	↑	++	↑	--	~
Real-time response time (µs)	1000	↑	1	↑	10	↑	100	↑	500	↑	100	↑	100	↑	10	↑	10	↑	1	↑
Level of concurrency	-	~	-	↑	+	↑	+	↑	+	↑	-	~	+	↑	+	↑	+	↑	+	↑
Hard real-time constraints	-	~	++	↑	+	~	+	~	+	↑	o	~	+	~	+	~	+	~	++	↑
Data communication	+	↑	+	↑	++	↑	+	↑	+	↑	o	~	+	~	++	~	o	~	++	↑
Control	-	↑	++	↑	++	↑	++	↑	++	↑	-	~	-	~	-	~	+	↑	-	~
Monitoring	+	↑	+	↑	+	~	+	↑	+	↑	+	↑	+	~	+	~	+	↑	+	↑
Device interfacing	+	↑	+	↑	+	↑	+	↑	+	↑	+	↑	+	↑	-	~	+	↑	+	↑
Data acquisition, signal processing	o	~	+	↑	-	↑	+	↑	+	↑↑	+	↑	+	↑	+	↑	+	~	+++	~
Level of robustness	+	~	++	~	+	~	+	~	++	~	-	~	+	~	+	~	+	~	+	~
Database	+	~	+	~	+	↑	+	~	+	↑	+	↑	o	~	+	↑	o	~	o	~

Context:

- Consumer product
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Consumer Products

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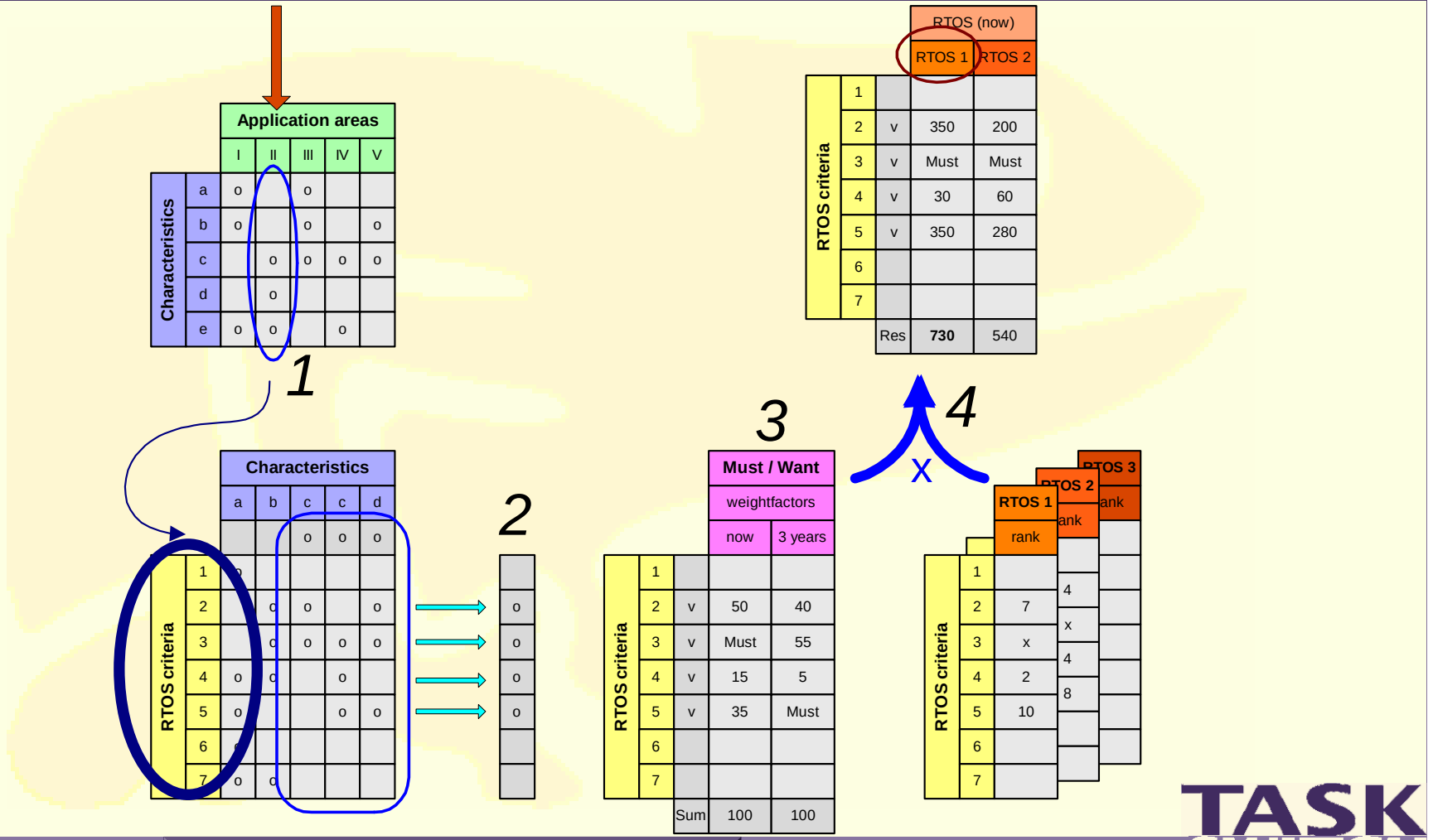
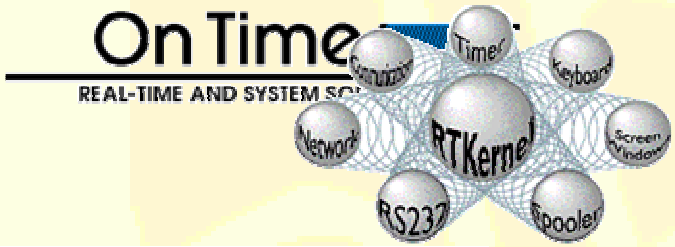
Development costs	+++	↑	++	↓	++	↑↑	++	↑	+++	↑
Product price	+	↑↑	++	↑	+	~	+	~	o	~
Upgradability	--	~	-	↑	--	~	--	↑	+	↑
Life span	--	↓	--	↓	-	↓	--	~	-	↓
Level of optimisation	+++	↓	+++	↓	+++	↓	++	↓	o	~
Succesive generations	+	↑	++	↑	o	~	o	↑	+	↑↑
Level of standardisation	++	↑	++	↑	-	↑	+	↑	+	↑↑
User interfacing	+	↑	++	↑	+	↑	o	↑	+	↑↑
Real-time response time (µs)	1000	↑	2000	↑	1000	↑	10	↑	100	↑
Level of concurrency	-	↑	-	↑	-	↑	+	↑	+	↑↑
Hard real-time constraints	-	~	-	~	-	~	++	↑↑	+	↑
Data communication	+	~	o	↑	o	~	o	↑	+	↑↑
Control	-	~	-	~	o	↑	+	↑	-	~
Monitoring	-	~	-	~	+	~	+	↑	-	~
Device interfacing	-	~	-	~	-	~	+	↑	+	↑
Data acquisition, signal processing	+	↑	+	~	-	↑	+	↑	+	↑
Level of robustness	-	~	-	~	-	~	++	~	-	~
Database	-	~	-	~	--	~	+	~	+	↑

RTOS characteristics



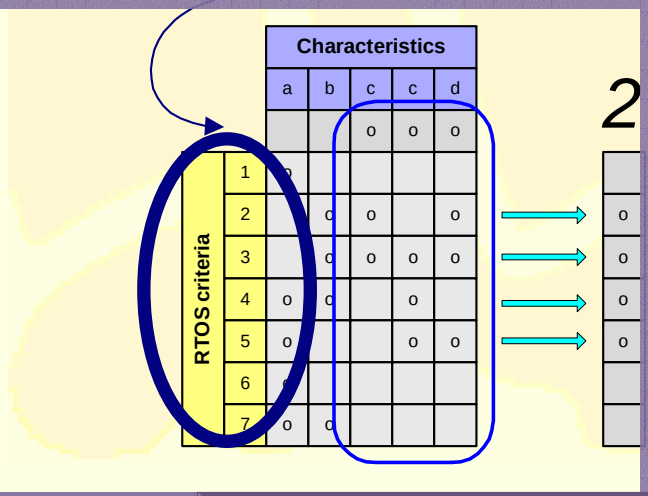
Real-Time Operating Systems



RTOS characteristics

GENERAL

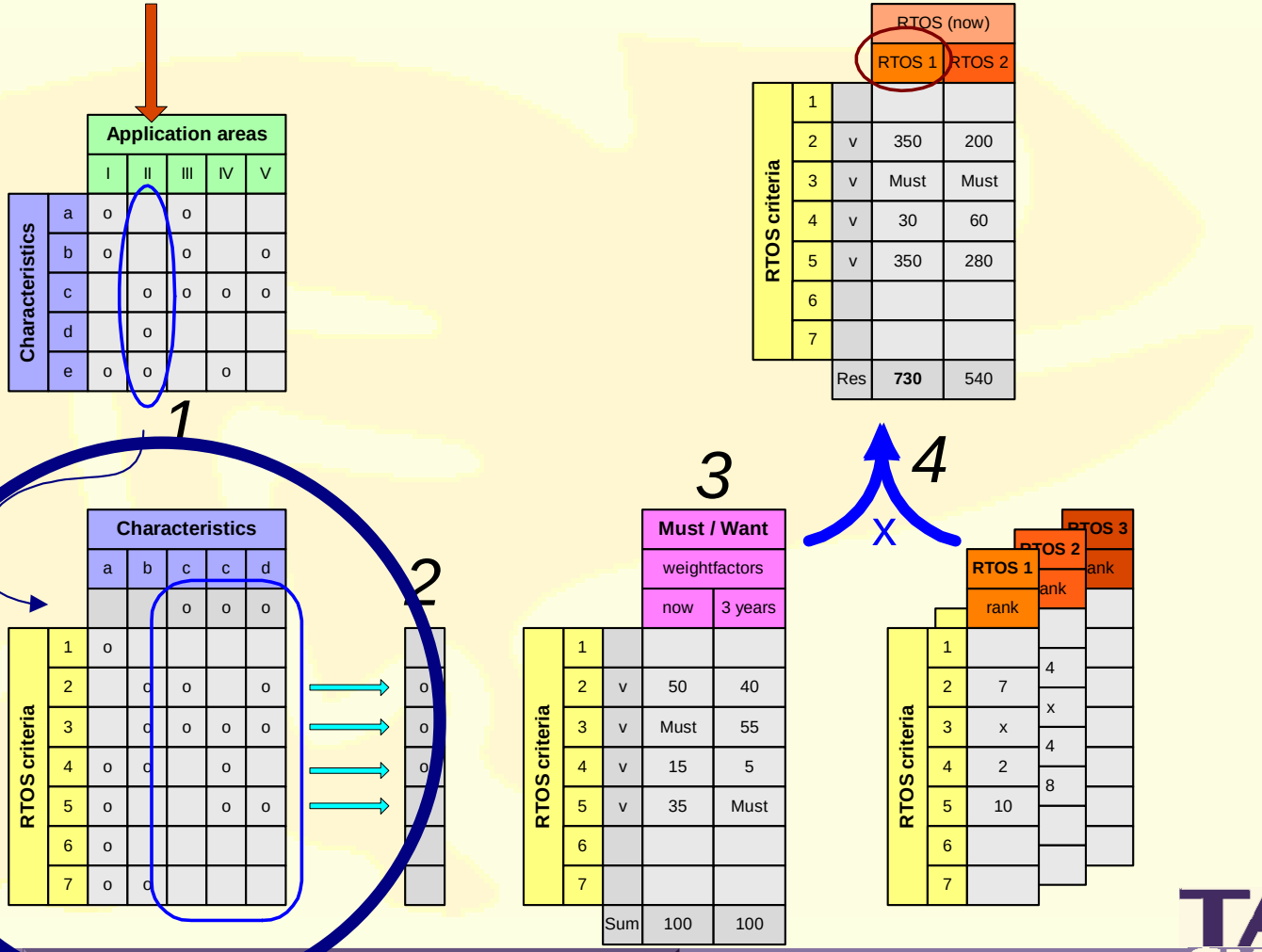
Supplier
Price / performance ratio
Development environment
Platform dependencies
Adherence to standards
Installed base
Quality of documentation
Product stability
Available expertise



TECHNICAL

Tunability
Scalability
Security
Multi-processor support
Memory management
File device I/O management
Interprocess communication
Synchronisation mechanismes
Process / thread support
Resource scheduling
Interrupt handling
Fine-grained performance
Application-oriented performance
Re-entrancy
Application Programming Interface (API)
Time management
Error / exception handling
ROM-ability
Data communication support
Peripheral driver support
User interface support
Database support
Compiler quality / efficiency

RTOS characteristics x Application characteristics



Context:

- Consumer product
- Multi-processor architecture
- High volume
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- Short market introduction window
- Contains pSOS+ / End-of-life

							Application Characteristics											
		Product price	Upgradability	Life span	Level of optimisation	Succesive generations	Level of standardisation	User interfacing	Real-time response time	Level of concurrency	Hard real-time constraints	Data communication	Control	Monitoring	Device interfacing	Data acquisition, signal processing	Level of robustness	Database
Development environment	o	o	o	+	o	o	+	o	o	o	o	o	o	o	+	o	o	o
Development environment	o	+	+	o	o	o	o	o	-	-	-	o	o	o	o	o	o	o
Development environment	o	+	+	+	+	+	+	+	o	o	o	+	+	+	+	+	o	+
Platform dependencies	o	+	o	o	+	+	+	o	+	+	+	o	o	o	o	o	o	o
Adherence to standards	o	+	o	+	+	-	+	+	o	o	o	+	o	o	+	+	o	+
Installed base	o	o	o	o	o	o	o	+	o	o	o	o	o	o	+	o	o	+
Quality of documentation	o	+	o	+	+	+	+	+	o	o	o	+	o	o	+	+	o	+
Product stability	+	+	o	+	+	+	o	o	o	o	o	+	+	+	+	+	+	o
Available expertise	o	+	o	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Technical criteria																		
Tunability	o	+	o	+	+	+	o	o	+	+	+	+	+	+	+	+	o	+
Scalability	+	-	+	+	+	+	o	+	o	o	o	+	o	o	o	o	+	o
Security	o	o	o	o	o	o	o	o	o	o	o	+	+	-	o	o	+	+
Multi-processor support	-	o	o	+	+	+	-	o	+	+	+	o	o	o	o	+	+	-
Memory management	+	o	+	o	o	+	o	o	o	+	o	o	o	o	o	o	+	+
File device I/O management	o	+	o	+	+	+	+	o	+	o	+	o	o	o	+	o	o	-
Interprocess communication	o	o	o	o	o	o	o	+	+	+	o	+	+	+	+	+	o	+
Synchronisation mechanismes	o	o	o	o	o	o	o	+	+	+	+	+	+	o	+	o	o	+
Process / thread support	o	+	o	+	+	o	o	+	+	+	+	+	+	+	+	+	+	+
Resource scheduling	o	o	o	+	+	+	o	o	+	+	+	+	+	+	+	+	+	o
Interrupt handling	o	o	o	o	o	o	o	o	+	o	+	+	-	o	+	+	-	-
Fine-grained performance	o	o	o	+	+	+	o	o	+	+	+	+	+	o	o	+	o	o
Application-oriented performance	o	o	o	+	+	+	o	+	+	+	+	+	+	o	+	+	+	o
Re-entrancy	o	o	o	+	o	+	+	o	o	+	+	o	+	o	o	o	o	+	o
Application Programming Interface (API)	o	+	o	+	+	o	o	+	o	o	o	+	+	o	+	o	o	+
Time management	o	o	o	o	o	o	o	+	+	+	+	+	+	+	+	+	o	-
Error / exception handling	o	+	o	o	o	o	o	+	o	+	+	+	+	o	+	+	+	o
ROM-ability	+	o	o	-	o	o	o	o	o	o	o	-	o	o	o	o	o	-
Data communication support	o	+	o	+	+	o	+	o	o	+	o	+	+	+	o	o	+	o
Peripheral driver support	o	+	o	+	o	o	+	+	+	o	o	o	o	+	+	+	o	-
User interface support	o	+	o	o	o	o	o	+	o	o	o	o	o	+	o	o	+	+
Database support	o	+	o	+	o	o	o	+	o	o	-	o	o	+	o	o	o	+
Compiler quality / efficiency	o	+	o	o	o	+	o	o	+	+	o	o	o	o	o	+	+	o

Kepner Tregoe

- Define the "musts"
- Distribute 100 % over remaining "wants"
- Both:
  - Now
  - E.g.: 3 years time

Musts & Wants

RTOS criteria	Now		3 years	
	Musts	%	Musts	%
Supplier		1		2
Price / performance ratio		2		13
Development environment	M			3
Platform dependencies	M		M	
Quality of documentation		12		1
Product stability	M		M	
Available expertise		10		17
Tunability		20		12
Scalability	M		M	
Multi-processor support	M			7
Memory management		17		9
File device I/O management		4		11
Interprocess communication	M		M	
Process / thread support		6		4
Resource scheduling		5		5
Interrupt handling	M		M	
Fine-grained performance		15		6
Re-entrancy	M		M	
Error / exception handling		5		10
ROM-ability	M		M	
Peripheral driver support		3	M	
Compiler quality / efficiency	M		M	
	Sum:	***100***	***Sum:***	***100***

Score results

RTOS criteria	Weighing F		pSOS+			VxWorks		
	Now	3 Yrs	BM	Sc N	Sc 3Y	BM	Sc N	Sc 3Y
Supplier	1	2	7	7	14	7	7	14
Price / performance ratio	2	13	4	8	52	4	8	52
Development environment	M	3	9		27	9		27
Platform dependencies	M	M	10			10		
Quality of documentation	12	1	3	36	3	6	72	6
Product stability	M	M	10			10		
Available expertise	10	17	10	100	170	2	20	34
Tunability	20	12	8	160	96	6	120	72
Scalability	M	M	9			9		
Multi-processor support	M	7	9		63	5		35
Memory management	17	9	8	136	72	9	153	81
File device I/O management	4	11	8	32	88	8	32	88
Interprocess communication	M	M	10			10		
Process / thread support	6	4	6	36	24	10	60	40
Resource scheduling	5	5	9	45	45	8	40	40
Interrupt handling	M	M	10			7		
Fine-grained performance	15	6	8	120	48	8	120	48
Re-entrancy	M	M	10			10		
Error / exception handling	5	10	7	35	70	9	45	90
ROM-ability	M	M	10			10		
Peripheral driver support	3	M	5	15		7	21	
Compiler quality / efficiency	M	M	10			7		
			Sum:	***730***	***772***	***Sum:***	***698***	***627***

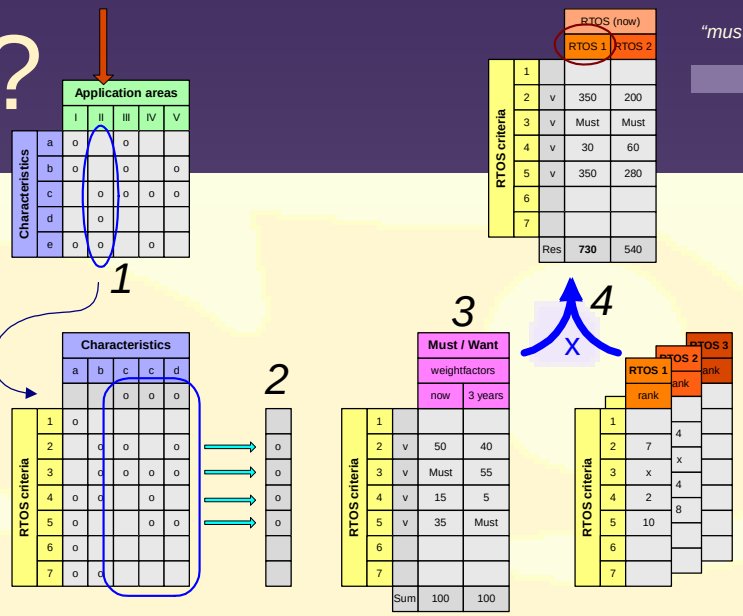
Devils advocate

RTOS criteria	Weighing F		pSOS+			VxWorks		
	Now	3 Yrs	BM	Sc N	Sc 3Y	BM	Sc N	Sc 3Y
Supplier	1	2	7	7	14	7	7	14
Price / performance ratio	2	13	4	8	52	4	8	52
Development environment	M	3	9		27	9		27

Statement	Probability	Seriousness
In the long term pSOS+ will disappear	HIGH	MEDIUM
Limited VxWorks experience of development team -> increase development costs	MEDIUM	LOW

Interprocess communication	M	M	10			10		
Process / thread support	6	4	6	36	24	10	60	40
Resource scheduling	5	5	9	45	45	8	40	40
Interrupt handling	M	M	10			7		
Fine-grained performance	15	6	8	120	48	8	120	48
Re-entrancy	M	M	10			10		
Error / exception handling	5	10	7	35	70	9	45	90
ROM-ability	M	M	10			10		
Peripheral driver support	3	M	5	15		7	21	
Compiler quality / efficiency	M	M	10			7		
			Sum:	***730***	***772***	***Sum:***	***698***	***627***

Is there a new future for the method?



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