# How a **Lightweight RTOS** can Drive **CubeSat Flight Software**

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### **Flight Software Requirements**

- Reliable Duh
- Modular so that multiple coders can work on it simultaneously
- (Re-)configurable e.g. for testing, or to optimize performance.
- Efficient use a minimum of RAM, Flash, power
- Fast satisfy responsiveness & throughput requirements
- Capable permit the use of (all) of the MCU's hardware / peripherals, without getting in the way
- Clean enable a consistent programming methology

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## What is an RTOS?

- A chunk of software that:
  - Has a well-defined API, clear documentation, etc.
  - Provides a variety of services to build an application on top of it:
    - Scheduling
    - Multitasking
    - Time-based services
    - Inter-process communication
  - Has 'soft' or "hard" real-time performance

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- Is configurable, extensible, etc.
- Has a user base of >
- Pumpkin's Salvo<sup>™</sup> RTOS is a lightweight RTOS designed for embedded MCUS (MSP430, PIC, C8051, etc.)



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## **Non-RTOS vs RTOS Coding**

- Non-RTOS applications:
  - Are typically very linear in their coding and execution
  - Typically don't have scheduling, priorities, etc.
  - Their run-time performance is typically strongly affected by additions / deletions to the code
  - Must often utilize interrupts heavily to achieve a modicum of responsiveness
  - Are initially smaller ... but eventually become larger than the RTOS equivalent

#### RTOS applications

- Are very loosely-coupled
- Leverage multitasking, priorities and scheduling to maximize responsiveness, minimize load and reduce power consumption
- Concentrate functionality via a few modules, ultimately reducing code size

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Have a very consistent look and feel to the code

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## Who uses (Embedded) RTOSes?

- Some Salvo RTOS applications:
  - Automated shrimp feeders in Patagonia
  - Industrial process controls
  - Health / fitness monitors
  - SDL's DICE mission
  - Sports watches
  - Bowling lanes
  - Electronic toys
  - Geotagging devices
  - Earth science sensors
  - SSDL's LMRST-Sat mission
  - All of Pumpkin's sub-Linux-size embedded controllers

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## Multitasking

OSInit();

OSCreateTask(task\_cmd.do, OSCreateTask(task\_scpi, OSCreateTask(task\_status, OSCreateTask(task\_led, OSCreateTask(task\_self\_test, OSCreateTask(task\_vinti7,

while (1) {
 OSSched();
}

TASK	CMD_P,	2);
TASK	SCPI P,	1);
TASK	STATUS P,	3);
TASK	LED_P,	15);
TASK	SELE TEST P,	5);
TASK	VINTI7 P,	8);



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#### **Periodic Task Execution**

void task\_TAP\_EPS\_temperature(void) {

TAP\_set\_name(TAP\_ID\_EPS\_TEMPERATURE, "EPS\_temperature"); TAP\_set\_interval(TAP\_ID\_EPS\_TEMPERATURE, TAP\_ID\_EPS\_TEMPERATURE\_INTERVAL\_DEFAULT); TAP\_set\_size(TAP\_ID\_EPS\_TEMPERATURE,

SIZEOF\_TAP ID EPS\_TELEM\_TEMPERATURE); TAP\_set\_action(TAP\_ID\_EPS\_TEMPERATURE, SEND\_TAP\_SDCARD); TAP\_set\_carton\_fn(TAP\_ID\_EPS\_TEMPERATURE, carton\_EPS\_temperature\_fill\_TAP);

while(1)

OS\_DelayTS(TAP\_get\_interval(TAP\_ID\_EPS\_TEMPERATURE)); TAP\_push\_TAP(TAP\_ID\_EPS\_TEMPERATURE); WDT\_inc\_counter(TAP\_ID\_EPS\_TEMPERATURE);



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#### Waiting with a Timeout

void task\_GPS\_timeout(void)\_ {

#### while(1)

OS\_WaitBinSem(BINSEM\_GPS\_TIMEOUT\_S\_P,OSNO\_TIMEOUT); OSTryBinSem(BINSEM\_GPS\_TIMEOUT\_E\_P); OS\_WaitBinSem(BINSEM\_GPS\_TIMEOUT\_E\_P,GRS\_TIMEOUT\_TIME); if(OSTimedOut()) { gps\_power(0);



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### **Managing Elapsed Time**

char \* time\_elapsed\_DDHHMMSSTT(void) { OStypeTick sec, tt; int dd, hh, mm, ss; static char str

tt	=	OSGet	Fcks();
sec	=	(tt 🍡	TICKS_PER_SEC);
dd	=	(sec	SEC_PER_DAY);
hh	=	(sec	SEC_PER_HOUR)
	-	(dd	HOUR PER DAY);
mm	=	(sec /	SEC PER MIN)
	-	(hh <	MIN_PER_HOUR) - (dd * MIN_PER_DAY);
SS	=	sec -	(mm * SEC_PER_MIN)
	-	(hh \star	SEC_PER_HOUR) - (dd * SEC_PER_DAY);
tt	=	tt%T]	ICKS_PER_SEC
dd	<b>%=</b>	100;	
spr	int	f(str	, "%02d:%02d:%02d:%02d.%02d", dd, hh, mm, ss, tt)

return str;



}

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;

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#### All it takes is one API call ...

}

void time\_ISR\_TimerA0(void) interrupt[TIMERA0\_VECTOR] {
 TACCR0 += SYSTEM\_TICK\_10ms;
 OSTimer();



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#### **ISR-to-task Communications**

void task cmd do(void) { unsigned char cmd;

while (1) {

OS WaitSem (SEM CMD CHAR P, OSNO TIMEOUT) if ((cmd=uart1 getchar())) switch (tolower(cmd))

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// H case explai Cmd. break;

attribute ((interrupt, no auto psv)) \_U1RXInterrupt(void) { void uart1 inchar(ReadUART1()); OSSignalSem(SEM CMD CHAR P);



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#### **Sleeping whenever Possible**

void OSIdlingHook(void) asm(" PWRSAV #1 ");

}

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#### **High Runtime Performance**

int main()

init(); i2c1 init(); I2C1 Msgs Received = 0;SCPI Init(&scpi context) scpi cmds =

[SNIP]

```
while (1)
  if (I2C1 Msgs Pending)
    //SCPI MESSAGE RECIEVED
    OSSignalBinSem (BINSEM SCPI RCVD P);
  if (I2C1STATbits.I2COV)
    //I2C OVERFLOW -- CLEAR AND RESET I2C1
    i2c1 init();
  OSSched();
```

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## Lightweight Footprint

Pumpkin GPSRM 1 v0.3.9 Flash Memory Utilization (PIC24EP256MC206 w/262,144 bytes Flash)



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Pumpkin GPSRM utility functions [478]

Microchip 16-bit self-test functions [1066]

Pumpkin SupMCU utility functions [1250]

□ Miscellaneous functions [1294]

 Pumpkin UART1 & UART2 library [1364]
 init(), main() & tasks [2318]

Pumpkin Salvo RTOS [2360]

 SCPI Command Processing [9816]
 Vinti7 Orbit propagator [27734]

C library functions [48353]

□ Free [166111]

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## Conclusion

- Pumpkin's lightweight Salvo RTOS has been used as the basis for flight software on multiple successful CubeSat missions
- A well-designed lightweight RTOS
  - Can have minimal impact on Flash and RAM
  - Can be exceptionally robust (see spaceflight heritage), in part because of its simplicity
  - Provides a wealth of useful features
  - Is conducive to team-based software development
  - Does not "get in the way" of real-time performance



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#### SPACE SYSTEMS

**Q&A** Session

ТΜ

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#### Notice

#### This presentation is available online at:

www.pumpkininc.com/content/doc/press/20150808\_Pumpkin\_CSDWLU\_2015.pdf



## Appendix

#### Speaker information

 Dr. Kalman is Pumpkin's president and chief technology architect. He entered the embedded programming world in the mid-1980's. After co-founding Euphonix, Inc – the pioneering Silicon Valley high-tech pro-audio company – he founded Pumpkin, Inc. to explore the feasibility of applying high-level programming paradigms to severely memory-constrained embedded architectures. He is the creator of the Salvo RTOS and the CubeSat Kit. He holds several United States patents. He is a consulting professor in the Department of Aeronautics & Astronautics at Stanford University and directs the department's Space Systems Development Laboratory (SSDL). Contact Andrew at aek@pumpkininc.com.

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products helps us continually improve and innovate.

#### CubeSat Kit information

More information on Pumpkin's CubeSat Kit can be found at <u>http://www.cubesatkit.com/</u>. Patented and Patents pending.

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