How a **Lightweight RTOS** can Drive CubeSat Flight Softwa

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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[™] 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_	SELF_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	=	OSGetTicks();
sec	=	(tt / TICKS_PER_SEC);
dd	=	(sec <u>SEC PER DAY</u>);
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 * SEC_PER_HOUR) - (dd * SEC_PER_DAY);
tt	=	tt%TICKS PER SEC;
		100;
spr	int	tf(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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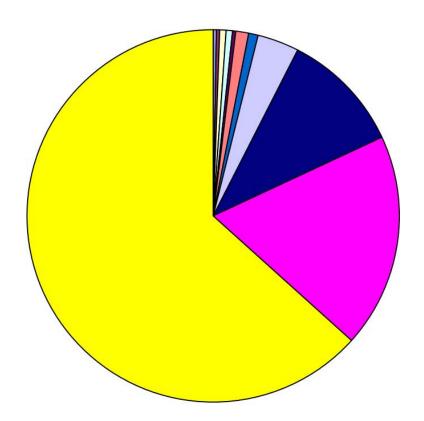
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Lightweight Footprint

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

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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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