

# G9 Impulse-NG

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## **Abstract**

Project G9 Impulse-NG is a derivation from the G9 Impulse: Video Game System project by Zuofu Cheng, James Cavanaugh, Eric Sands, Sean Bires, and Chris Schmich during the Fall 2005 and Spring 2006 semesters. As the original gaming system was a project from almost 5 years ago, this project's aim was to import the whole system to more modern hardware platform and extend its capabilities. The Altera DE2 was chosen as the target platform due to ECE students' relative familiarity with said platform. Due to obstacles encountered and time constraints, a complete port of the system remains unfinished. The G9 Impulse-NG currently only supports drawing a single frame with alpha blending for drawing sprites.

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# 1 Project Description and Overview

## 1.1 G9 Impulse (The Original System)

The original G9 Impulse was an 8-bit, 2D gaming system. It can use an NES controller or custom arcade controls as input and outputs to a CRT monitor at a 320x240 resolution using interlacing mode. It has 2-bit DAC for each of the red, blue, green colors, allowing a total of 64 colors. Audio is provided through an MP3 player via standard 3.5mm audio jack. For further details, please take a look at the original G9 Impulse report at [https://courses.engr.illinois.edu/ece395/projects/spring2006/project9\\_final\\_paper.doc](https://courses.engr.illinois.edu/ece395/projects/spring2006/project9_final_paper.doc).

## 1.2 G9 Impulse-NG

The G9 Impulse-NG is still an 8-bit, 2D gaming system, but with extended hardware capabilities. It uses the Altera DE2 FPGA board which supports 10-bit DAC video out for each of the red, blue, green colors as opposed to the 2-bit DAC on the original system. Also, it is designed to output to an LCD monitor without interlacing at a 640x480 resolution. Currently, it does not support audio.

## 1.3 Tools Used

The primary tool used in this project was the Quartus II 9.1/10.0 which can be downloaded from the Altera website. It was used to compile the VHDL code and to program the Altera DE2 board. Also, the MegaWizard Plug-In Manager and NIOS II SOPC Builder under the tools tab in Quartus II were used to generate some of the required entities. ModelSim-Altera 6.5b Starter Edition, which can also be downloaded on the Altera website, was used to simulate the entities and aid in debugging.

In terms of hardware, the project utilized the Altera DE2 Development and Education Board for the GPU and the PIC18F4620 as the CPU.

## 1.4 Description of GPU Components

Most of the work was done on the Altera DE2 FPGA board which is the graphics processing unit of the game system. The following are the components inside the GPU chip on the Altera DE2 board.

### GPU Chip (gpuchip.vhd)

The gpuchip is the top level entity inside the Altera DE2 board. It takes instructions through the pin\_port\_addr and pin\_port\_in ports as inputs from an external PIC18F4620 microprocessor (CPU) and marshalls the information to be used as operands for the blitter. When the blitter operation is done, the gpuchip signals back to the PIC that the operation has been completed.

To use the gpuchip, appropriate registers must be loaded with all the information required by the blitter to begin its operations. As the data port is only 8-bits wide, the information is passed from the PIC to the gpuchip in multiple cycles. One should load `pin_port_addr` with the address of the register and the `pin_port_in` with the data, then raise the `pin_load` to signal the gpuchip to update the register. Table 1 shows the list of addresses and corresponding registers.

Address	Register
0000-0010	Source Address MSB-LSB
0011-0101	Target Address MSB-LSB
0110	Source Lines
0111	Line Width in pixels/2
1000	Alpha Op Register
1001	Double Buffer Enable
1010	Front Buffer Register

Table 1: GPU Instruction Set (from G9 Impulse Final Documentation)

Figure 1 shows the internal state machine of gpuchip. During the INIT state, the blitter is reset for its first time use. In the LOAD state, the registers are loaded when the `pin_load` is high. Then it continues onto the DRAW state when `pin_start` is asserted high. In the DRAW state, the gpuchip instructs the blitter to begin its drawing operations. When the blitter raises the `blit_done` signal, the gpuchip moves onto the REST state where it resets the blitter once more for next usage and signals the PIC that it is ready to accept the next command.

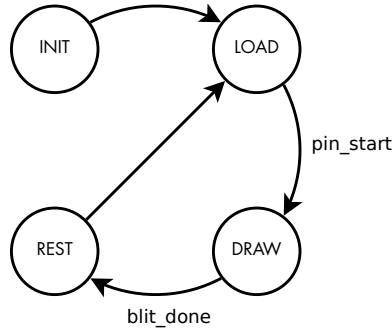


Figure 1: GPU State Diagram

Figure 2 shows the overall connections inside the gpuchip. However, due to connection problems in the hardware wiring from the DE2 board to external devices, the current system does not utilize the connections between the PIC18F4620 microprocessor. In particular, we believe 40-pin connector cable

connecting the DE2 board and the breadboard where the PIC resides does not form a stable connection. Also, there is crosstalk among the wires of the cable.

## Blitter

The blitter facilitates transferring large amounts of data in memory, from the sprite sheet to the framebuffer. Operands for the blitter are provided by registered inputs from the GPU, which ultimately originate from the PIC. The blitter uses the operands and reads the appropriate bytes from the sprite sheet and blits them onto the framebuffer. The blitter supports alpha blending which enables it to have transparent pixels in a square sprite region.

The operands required to operate the blitter are given in table 2.

Operand	Description
Source Address	Address in sprite sheet to blit from
Target Address	Address in framebuffer to blit to
Source Lines	Number of rows to blit
Line Width in pixels/2	Width of each row (divided by two because each word in the SDRAM stores data for two pixels)
Alpha Op	Whether or not to enable alpha blending
Front Buffer	Specifies which framebuffer to draw to

Table 2: Blitter Operands

The architecture of the G9 Impulse-NG was redesigned and resembles the original G9 Impulse blitter only in function and I/O. Originally, the sprite sheet and framebuffer both existed in the SDRAM. However, due to complications in reading and writing to the SDRAM without a dualport module for the Altera SDRAM controller, the SRAM was used to hold the framebuffer. Using the SRAM also has the advantage of simplicity and speed, as writes to the SRAM can be completed within one clock cycle. As the SRAM must also be used by the view entity to calculate the appropriate colors to output to the VGA device, so access to the SRAM must be arbitrated. To make sure there are no conflicts in using the SRAM, the view entity sends a `sram_waitrequest` to block writes while the screen is being drawn. Particularly, since the VGA is only drawing the framebuffer to the upper left quadrant of the screen, the blitter is allowed to write when the VGA is drawing the bottom half of the screen. Figure 3 shows when the blitter is allowed to write to SRAM.

The blitter is comprised of two processes and a queue. One of the processes reads sprites from the sprite sheet and puts the data into the queue. The other process reads from the queue and writes the data into the framebuffer when the blitter is given permission to do so. A diagram of the interaction is given in figure 4.

This design was chosen to take advantage of being able to read from the sprite sheet and write to the framebuffer simultaneously. In the original G9

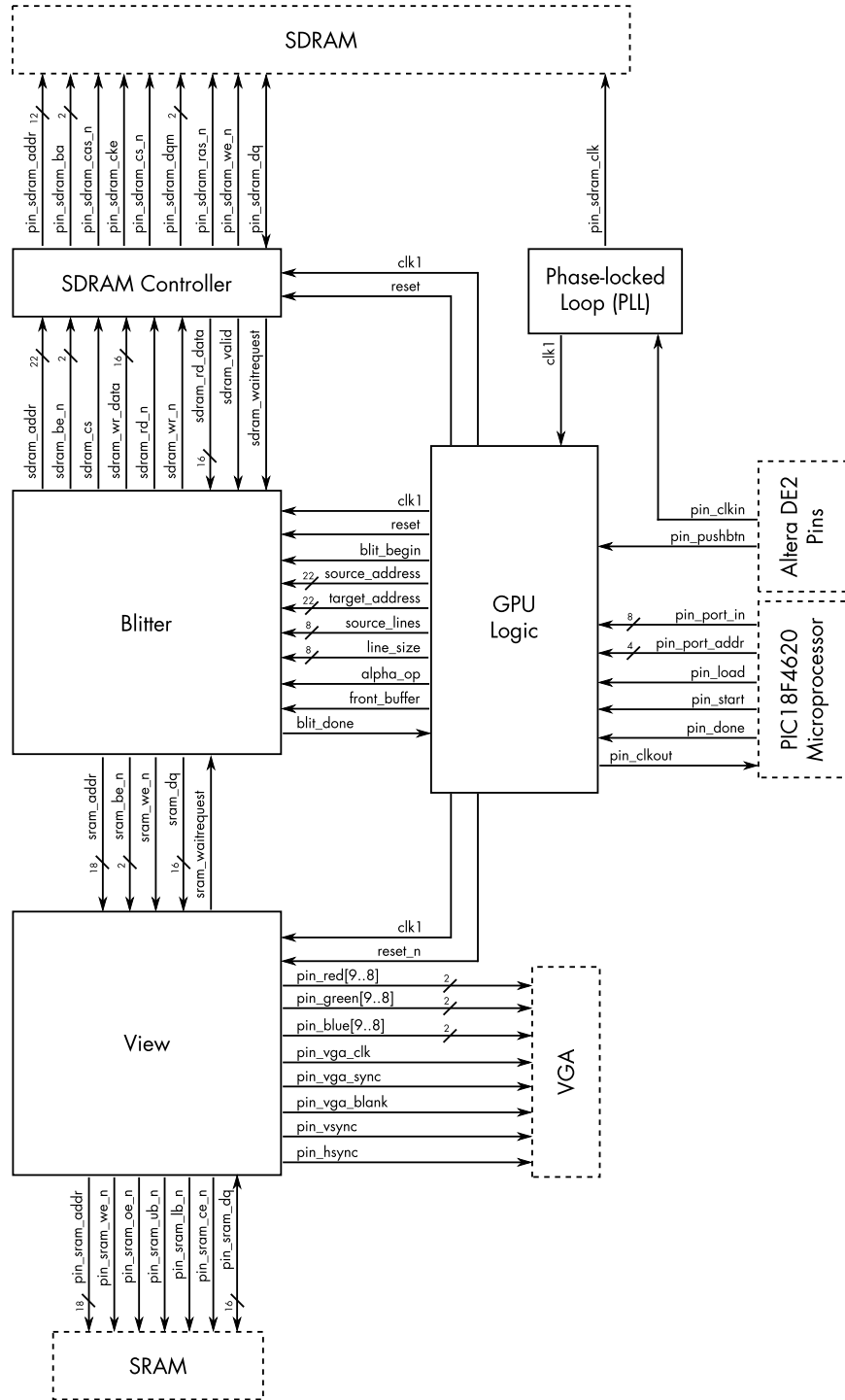


Figure 2: Block diagram of G9 Impulse-NG

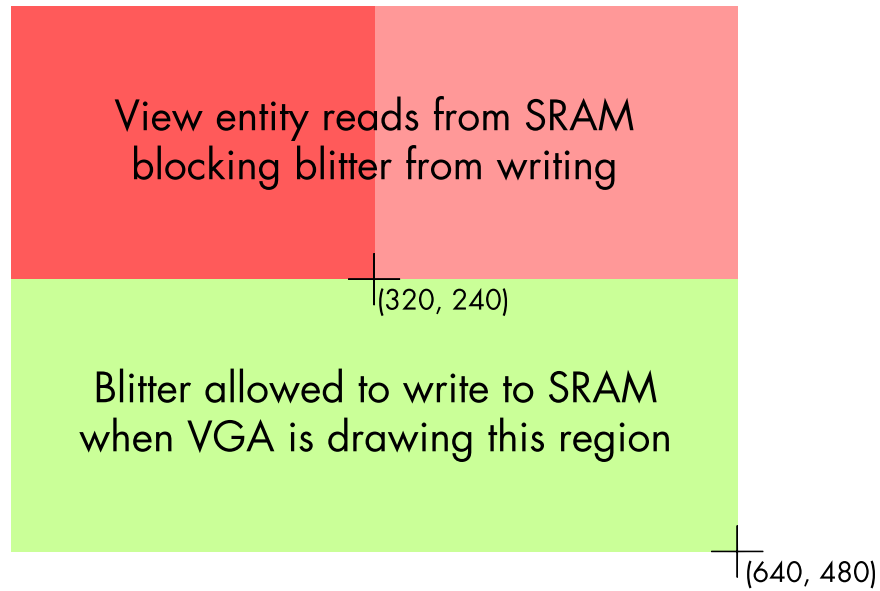


Figure 3: How SRAM access from blitter and view is divided

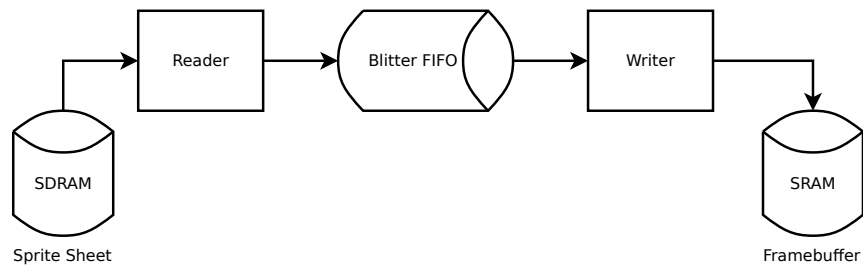


Figure 4: Diagram of how the blitter works

Impulse, this was not possible because both operations would involve accessing the SDRAM, but since the G9 Impulse-NG uses the SRAM for the framebuffer, using this architecture results in a slight speed increase because reads and writes can occur simultaneously.

Since reads from the SDRAM are pipelined, data is available several cycles after a read is issued. Using the queue allows the blitter to catch all the data read from the SDRAM independent of whether the writer is able to write the data immediately. When the VGA is drawing the screen, the writer will be blocked from accessing the framebuffer. With the queue in place, though, the reader will still be able to read from the sprite sheet until the queue is full.



Again, because of pipelining, data may arrive even after read is deasserted. Thus, the queue must always have enough room to accept the data. Therefore, an ‘almost full’ signal determines whether or not reads are allowed.

State diagrams for the blitter is given in figure 5.

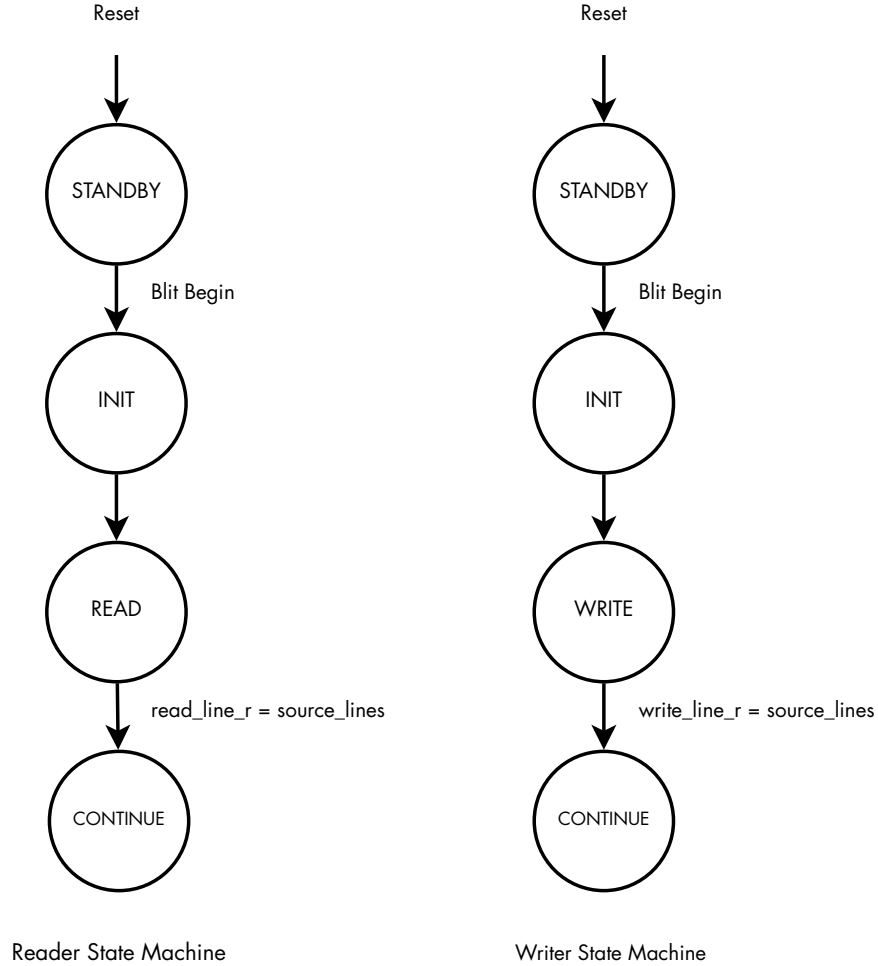


Figure 5: Blitter state diagrams

The two processes behave almost identically except for the direction of data flow and the conditions which allow the process to operate. When in the STANDBY state, the two processes wait for the blit\_begin signal to begin processing. Upon receiving the signal, various registers are loaded/reset with information about the source address, target address, current row being read/written, and current position being read/written in the current row. During the READ and WRITE states, the two processes respectively read from the

sprite sheet and write to the framebuffer. Reads occur when the queue is not full and the SDRAM waitrequest is not asserted. Writes occur when the queue is not empty and the SRAM waitrequest is not asserted. Both processes finish when the number of lines read/written is equal to the number of source lines.

Due to two pixels being stored in each sprite sheet address, the original G9 Impulse implemented alpha blending by reading both from the framebuffer and from the sprite sheet and blitting one or both pixels based on the color and the value of the alpha op operand. The Xilinx SDRAM controller used by the G9 Impulse did not support writing and reading to only one byte of the two byte memory location. The SRAM used by the G9 Impulse-NG however does support a byte enable signal. Thus, the G9 Impulse-NG blitter is able to perform alpha blending without reading back from the framebuffer. The result of this is that when blitting large sprites with alpha blending on, the new blitter will be faster because there will be less memory accesses.

When finished blitting, the blitter asserts the blit\_done signal. To blit another sprite, the blitter must be reset. The logic inside the GPU chip takes care of handling the blit\_done signal and resetting the blitter between operations.

### **Blitter FIFO (blitter\_fifo.vhd)**

The blitter fifo entity is a 512-byte, First-In First-Out buffer created by the Altera MegaWizard tool. It is implemented on the M4K memory block on the FPGA board. The buffer keeps track of current level of usage. Using this information, the blitter when it is allowed to read and write.

### **View (view.vhd)**

The view entity handles outputs to the LCD monitor. It generates the vertical sync, horizontal sync, and blank signals for the LCD monitor to use and the appropriate RGB values that go with the current pixel position on the screen. The view entity uses the on-board asynchronous SRAM as the framebuffer for fast access and allows the blitter to write to the SRAM when the SRAM is not being read. The subcomponents of the view entity include the VGA controller (VGA\_controller.vhd) and Color Mapper (Color\_Mapper.vhd).

### **VGA Controller (VGA\_controller.vhd)**

The vga\_controller entity takes a 50 MHz clock as its input and generates a 25 MHz clock which acts as the pixel clock and the appropriate horizontal and vertical sync pulses. It also outputs the current coordinates on the screen as DrawX and DrawY. The code is sourced from Lab 9 of the ECE 385 (Digital Systems Laboratory) course at the University of Illinois at Urbana-Champaign.

### **Color Mapper (Color\_Mapper.vhd)**

The Color Mapper entity takes the current coordinates on the screen and decides which color to draw on the screen. Currently, the G9 Impulse-NG outputs at

a 640x480 resolution, but it only uses the upper left quadrant of the screen (320x240) for actually displaying the game, virtually keeping the same resolution as in the original system. The Color Mapper outputs the actual game if the current pixel is in the upper left quadrant. Otherwise, it just outputs a blue color.

### **Dualport RAM (ram2port.vhd)**

The ram2port entity is a 512-byte, 2-port memory block created by the Altera MegaWizard tool. It uses the onboard M4K memory and supports simultaneous reads and writes. It is used inside the fifo\_cc entity to implement a First-In, First-Out buffer.

### **FIFO (fifo\_cc.vhd)**

The fifo\_cc entity is a 512-byte, First-In First-Out buffer that uses the ram2port entity as its component. It keeps track of current level of usage. Originally, the blitter utilized the blitter FIFO to queue pixel data. However, a bug was discovered to be fixed when the fifo\_cc was utilized instead. Both FIFOs provide signals to tell the blitter when reads and writes are allowed.

### **Phase-Locked Loop (sdram\_pll.vhd)**

The sdram\_pll is the phase-locked loop entity to ensure proper delay between the system clock and the SDRAM clock. The SDRAM clock needs to be advanced by 3ns with respect to the system clock for it to function properly. The PLL entity was generated by the Altera MegaWizard tool.

### **SDRAM Controller (sdram\_0.vhd)**

The sdram\_0 entity is the SDRAM controller generated by the NIOS II SOPC Builder in Quartus II. It follows the Avalon Memory-Mapped Interfaces specification as outlined in [http://www.altera.com/literature/manual/mnl\\_avalon\\_spec.pdf](http://www.altera.com/literature/manual/mnl_avalon_spec.pdf). Out of the 22-bit address it takes as input, it uses bits 21 and 8 for the bank address, bits 20 down to 9 as the row address, and bits 7 down to 0 as the column address. One should note that this format for decoding address is different from the one they use in the DE2 Control Panel program which can be used to write data into the SDRAM. The DE2 Control Panel uses bits 21 down to 20 as the bank address, bits 19 down to 8 as the row address, and bits 7 down to 0 as the column address.

### **Hex Display Driver (HexDriver.vhd)**

The HexDriver entity takes 4-bit number as its input and outputs a 7-bit vector that can drive the onboard 7-segment display. The code was sourced from ECE 385 class. This entity is not an integral part of the GPU and was used only for debugging purposes.

## 1.5 Description of Software Components (Starcell XF-1 Game)

The original G9 Impulse came with vertical scrolling shooter arcade game written for the system titled Starcell XF-1. The game code runs on the PIC18F4620 microprocessor which is the main CPU of the system. The game code was not actually utilized because of signal crosstalk when wiring the DE2 board with the PIC. Particularly, the ribbon cable used to connect the 40-pin expansion header on the DE2 board to the protoboard which contains the PIC18 and other related components seemed to distort and attenuate the signals. However, images from the game was converted into a binary file and used extensively in testing functionalities of gpuchip.

## 2 Results

Most of the time devoted to the project was spent on figuring out how to use the SDRAM on the Altera DE2 board. There were no SDRAM controllers in VHDL provided by the manufacturer or good documentation on what the NIOS II generated SDRAM controller does, so there had been a lot of guesswork going into how to use the SDRAM controller. There had also been an attempt to use the Xilinx XSB SDRAM controller on the DE2 board, but this approach was dropped after realizing that the Altera DE2 board does not have hardware support for delay-locked loops. Using ModelSim to simulate these controllers aided greatly in having breakthroughs towards the end of the semester. After getting the NIOS II controller working, it was noticed that the screen was scrambled. The problem was found to be the way the address is decoded inside the DE2 Control Panel which is used to initialize contents of the SDRAM is different from the way the address is decoded inside the SDRAM controller which reads out of the memory. After fixing this issue, the vga entity and the blitter was redesigned to integrate the corrected usage of the SDRAM controller, but there was not enough time left for debugging the glitches in the synchronization between components. Also, the PIC18F4620 hardware had to be left out of the picture because of bad connection cable. The blitter contains a bug that causes the writer to never reach the CONTINUE state, though on screen, the blit appears to be completed. We speculate the bug could be caused by reading and writing to a nearly empty queue at the same time. Perhaps the issue can be fixed by having the blitter writer only operate when the queue size is above a minimum threshold. Due to the aforementioned problems, the current G9 Impulse-NG hardware can display a static frame alpha blended onto the framebuffer.

## 3 Future Development

As it has been discovered how to access the SDRAM and other required components inside the gpuchip, if the synchronization issue between these components can be resolved, it should be relatively easy to display a scrolling background and draw sprites that move around. Audio may be added using the onboard support for an audio output. However, it has not been tested if the expansion headers can be used to correctly receive external inputs into the DE2 board, so there may still be some difficulty in interfacing the board with a PIC18. It is advised that a future developer continuing this project consider using a Xilinx FPGA board rather than the Altera board, as Xilinx provides more resources and documentation for developers.

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