Input/Output Systems

Processor needs to communicate with other devices:

- Receive signals from sensors
- Send commands to actuators
- Or both (e.g., disks, audio, video devices)

I/O Systems

Communication can happen in a variety of ways:

- Binary parallel signal
- Serial signals
- Analog

An Example:
SICK Laser Range Finder

- Laser is scanned horizontally
- Using phase information, can infer the distance to the nearest obstacle (within a very narrow region)
- Spatial resolution: ~.5 degrees, 1 cm
- Can handle full 180 degrees at 20 Hz

Serial Communication

- Communicate a set of bytes using a single signal line
- We do this by sending one bit at a time:
  - The value of the first bit determines the state of a signal line for a specified period of time
  - Then, the value of the 2^{nd} bit is used
  - Etc.

Serial Communication

The sender and receiver must have some way of agreeing on when a specific bit is being sent

- Typically, each side has a clock to tell it when to write/read a bit
- In some cases, the sender will also send a clock signal (on a separate line)
- In other cases, the sender/receiver will first synchronize their clocks before transfer begins

Asynchronous Serial Communication

- The sender and receiver have their own clocks, which they do not share
- This reduces the number of signal lines
- Bidirectional transmission, but the two sides do not need to be synchronized in time

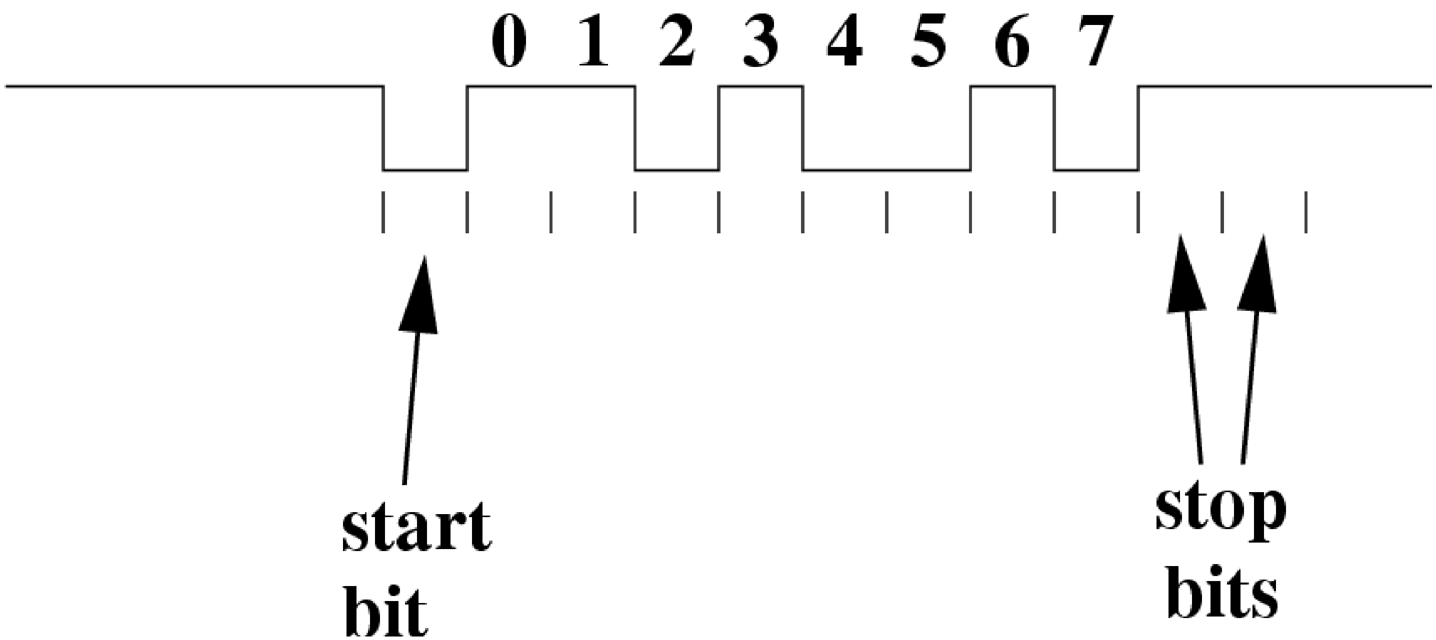
But: we still need some way to agree that data is valid. How?

Asynchronous Serial Communication

How can the two sides agree that the data is valid?

- Must both be operating at essentially the same transmit/receive frequency
- A data byte is prefaced with a bit of information that tells the receiver that data is coming
- The receiver uses the arrival time of this **start bit** to synchronize its clock

A Typical Data Frame



The stop bits allow the receiver to immediately check whether this is a valid frame

- If not, the byte is thrown away

Data Frame Handling

Most of the time, we do not personally deal with the data frame level. Instead, we rely on:

- Hardware solutions: Universal Asynchronous Receiver Transmitter (UART)
  - Very common in computing devices
  - Software solutions in libraries

Frame-Level Error Detection

- Due to timing and noise problems, the receiver may not receive the correct data
- We would like to catch these errors as early in the process as possible
- The first line of defense: include extra bits in the data frame that can be used for error detection and/or correction
  - This can also be done by our UART

Frame-Level Error Detection

Parity bit: indicates whether there is an odd or even number of 0s in the byte

- Transmitter computes the parity bit and includes it in the data frame
- Receiver also computes parity of the received byte
- If the two do not match, then an error is raised
  - How the error is dealt with is determined by the meta-level protocol

Frame-Level Error Correction

- When we use a single parity bit, we assume that in the worst case, a single bit is corrupted
- But: we can be more sophisticated about catching errors if we transmit more bits (at the cost of a larger data frame)
- Instead, we tend to do these types of checks on a set of bytes: “checksum”s

One Standard: RS232-C

Defines a logic encoding standard:

- “High” is encoded with a voltage of -5 to -15 (-12 to -13V is typical)
- “Low” is encoded with a voltage of 5 to 15 (12 to 13V is typical)

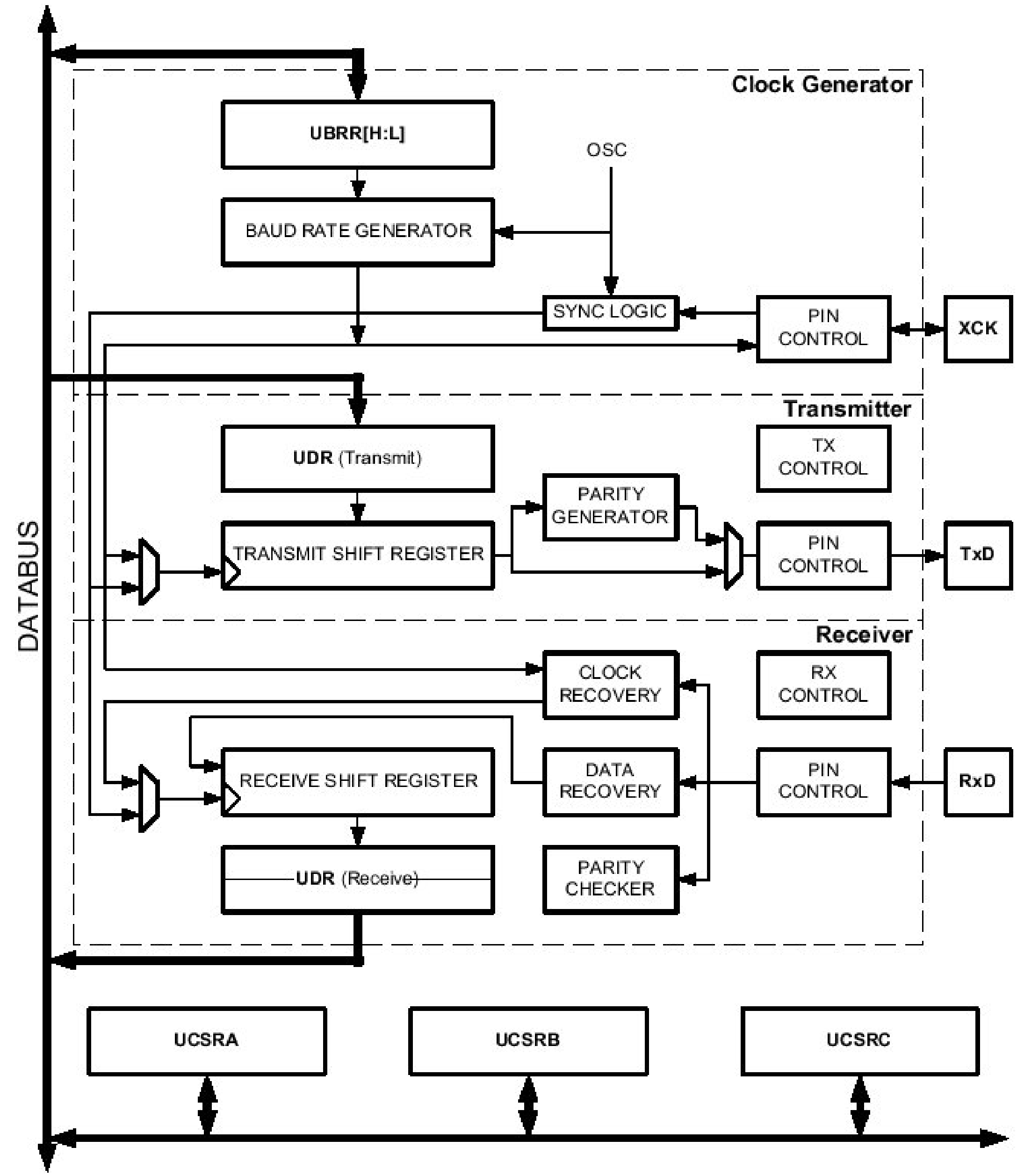
RS232 on the Mega8

Our mega 8 has a Universal, Asynchronous serial Receiver/Transmitter (UART)

- Handles all of the bit-level manipulation
- You only have to interact with it on the byte level

But: “Low” is 0v and “High” is +5V

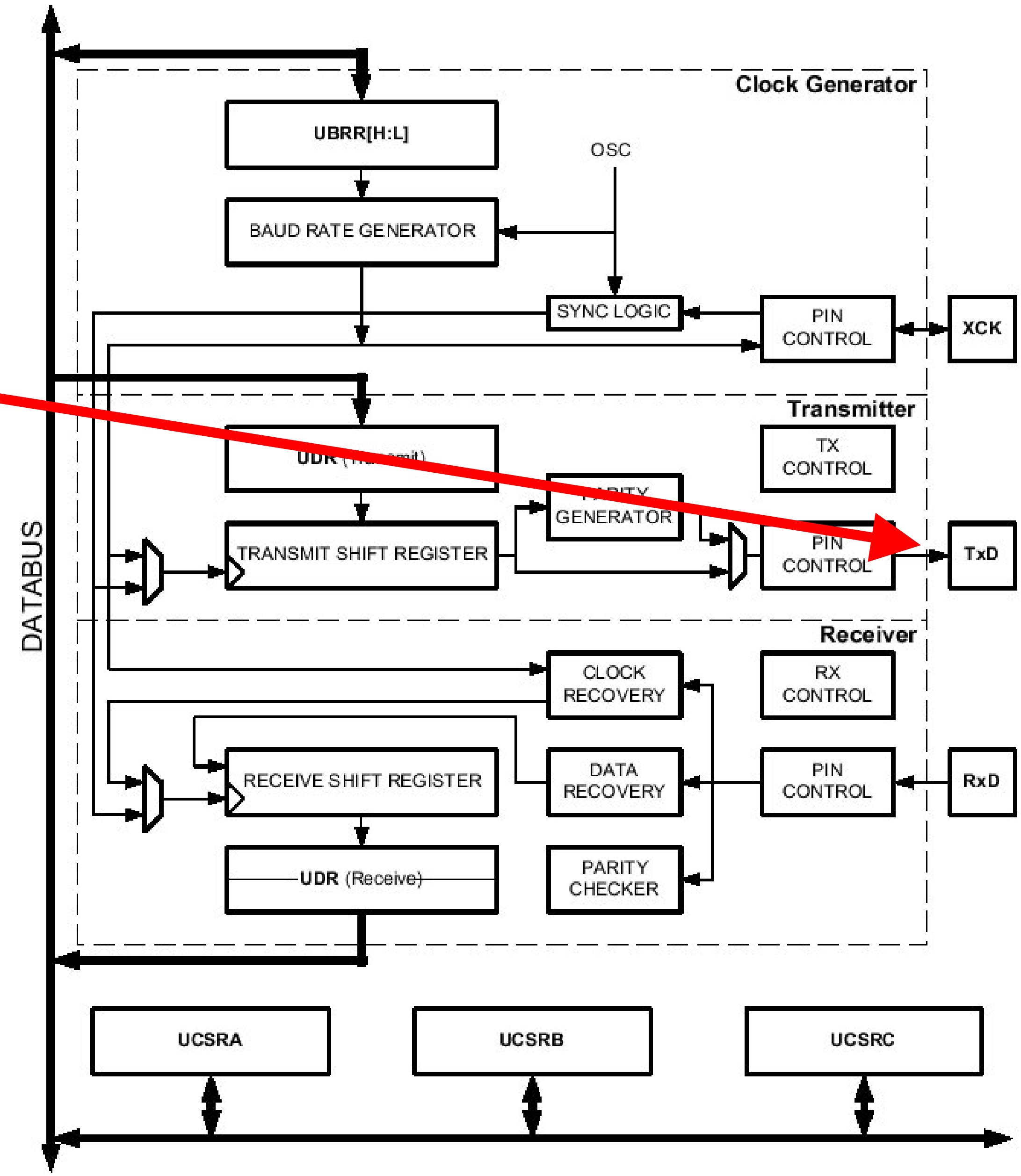
Mega8 UART



Clock Generator
UBRR[H:L]
OSC
BAUD RATE GENERATOR
SYNC LOGIC
PIN CONTROL
XCK
Transmitter
TX CONTROL
UDR (Transmit)
PARITY GENERATOR
TRANSMIT SHIFT REGISTER
PIN CONTROL
TxD
DATABUS
Receiver
CLOCK RECOVERY
RX CONTROL
RECEIVE SHIFT REGISTER
DATA RECOVERY
PIN CONTROL
RxD
UDR (Receive)
PARITY CHECKER
UCSRA
UCSRB
UCSRC

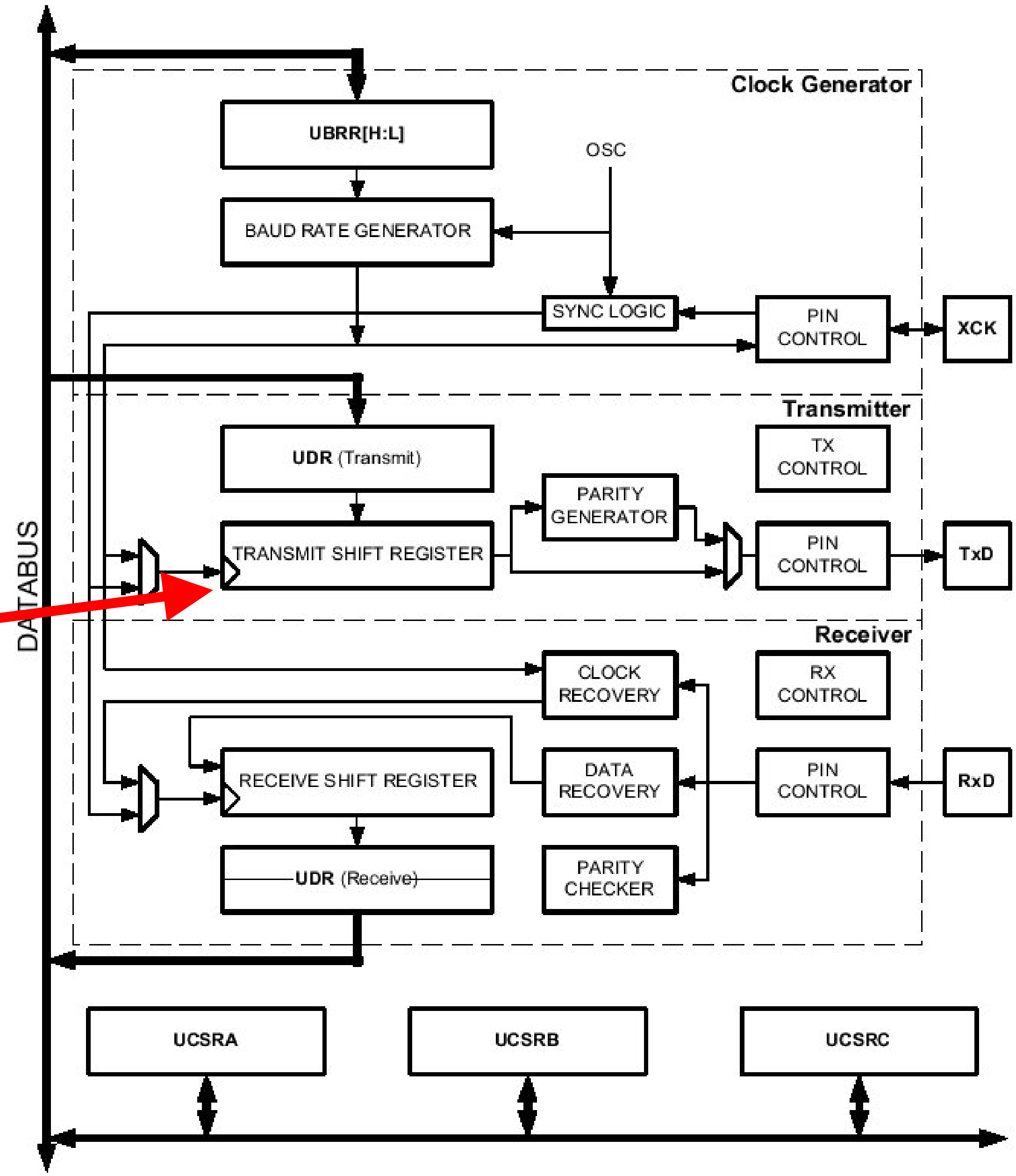
Mega8 UART

- Transmit pin (PD1)



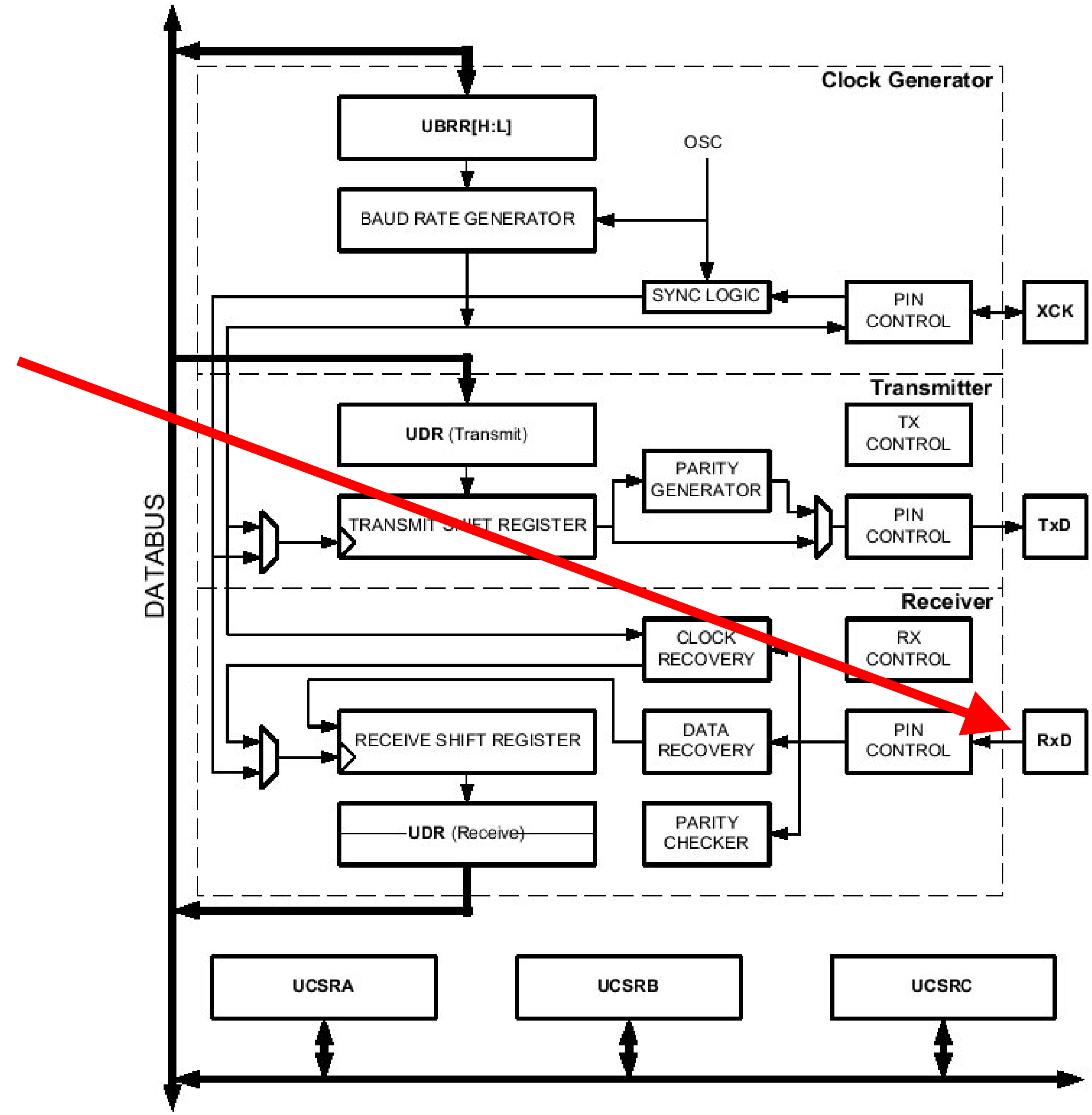
Mega8 UART

- Transmit pin (PD1)
- Transmit shift register



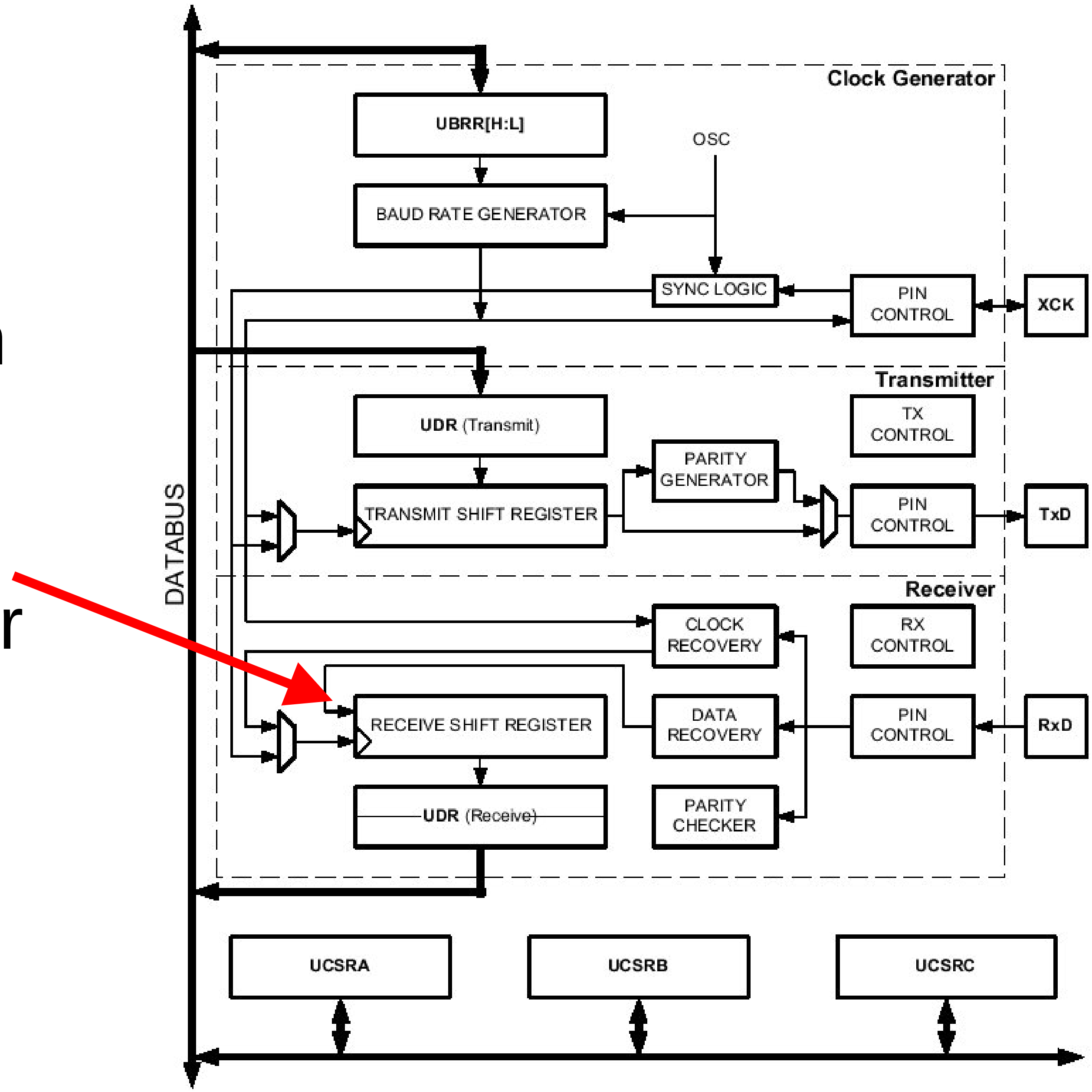
Mega8 UART

- Receive pin (PD0)



Mega8 UART

- Receive pin (PD0)
- Receive shift register



Mega8 UART C Interface

Lib C support (standard C):

`getchar()`: receive a character

`putchar('a')`: put a character out to the port

`puts("foobar")`: put a string out to the port

`printf("foobar %d %s", 45, "baz")`: put a formatted string out to the port (not recommended for the atmels)

Mega8 UART C Interface

OUlib support:

`fp = serial_init_buffered(0, 9600, 10, 10)`

Initialize the port @9600 bits per second (input and output buffers are both 10 characters long)

`serial_buffered_input_waiting(fp)`

Is there a character in the buffer?

See the Atmel HOWTO: examples/serial

Summary: Using OUlib + LibC

- At the top of your source file:

```
#include "oulib_serial_buffered.h“
```

- Initialization (in your main() function):

```
fp = serial_init_buffered(0, 9600, 10, 10)
sei();
```

- Getting a character:

```
char c;
C = getchar();
```

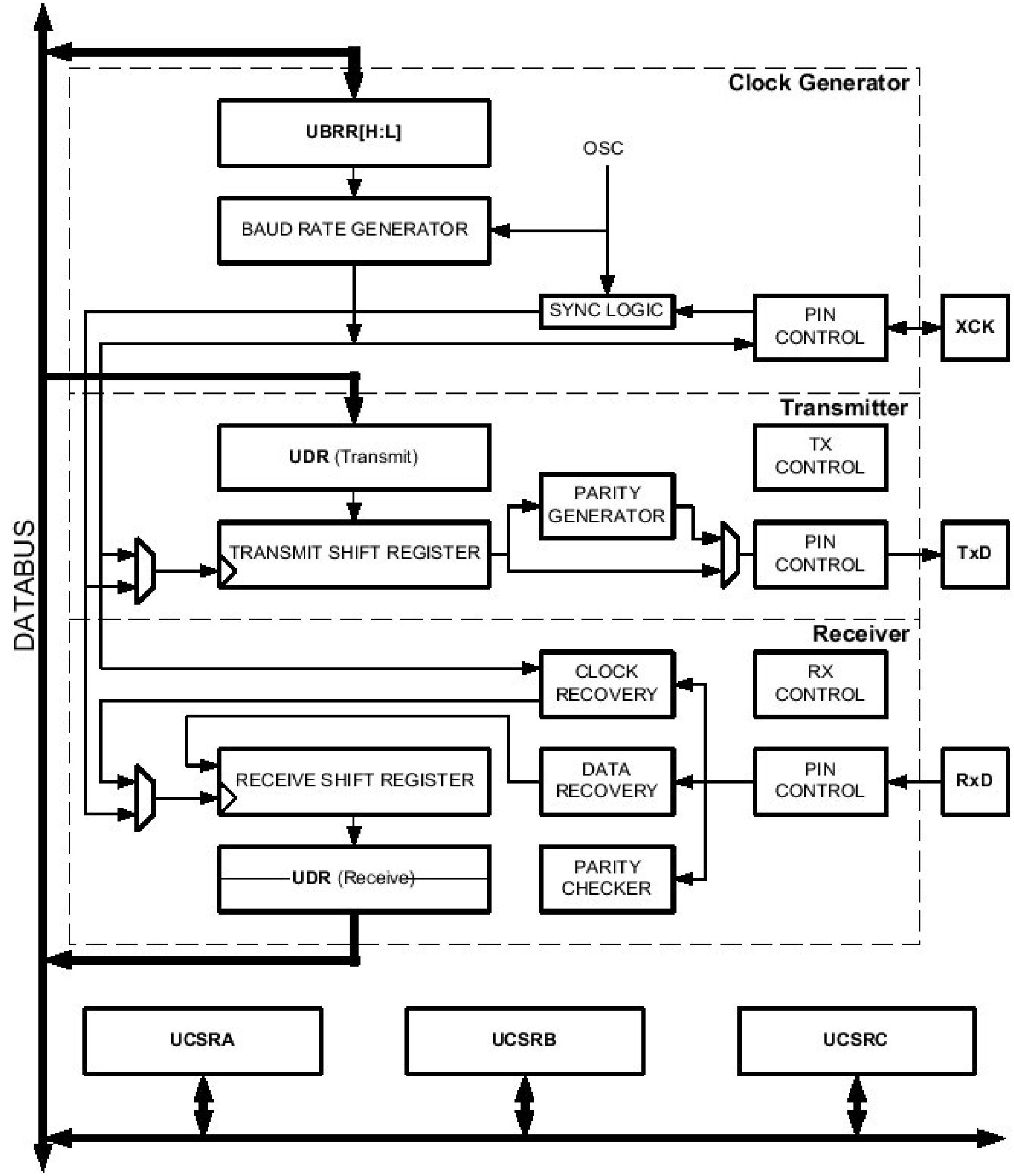
- Sending a character:

```
putchar(’f’);
```

Mega8 UART

putchar('c')

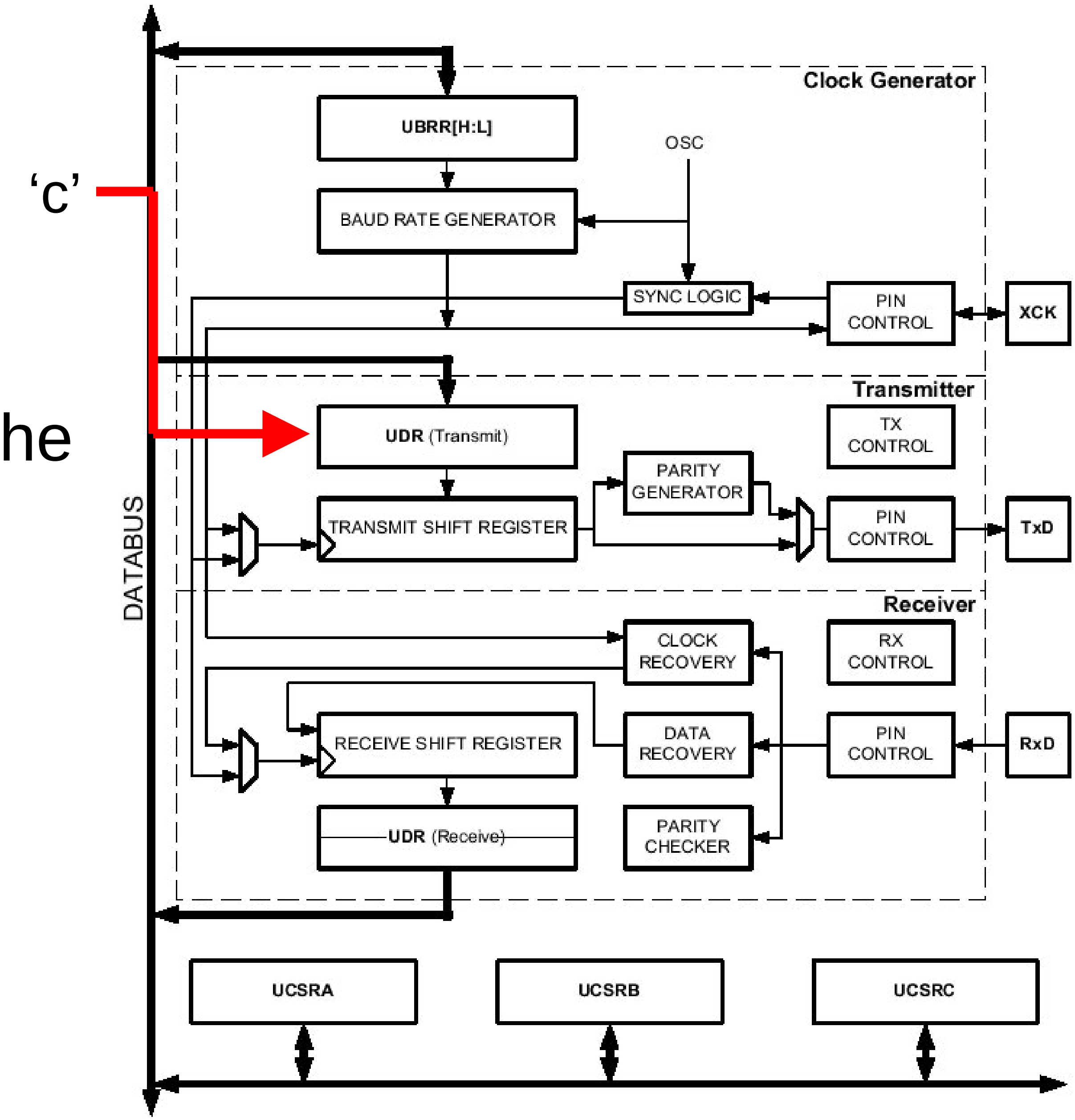
'c'



Mega8 UART

putchar('c')

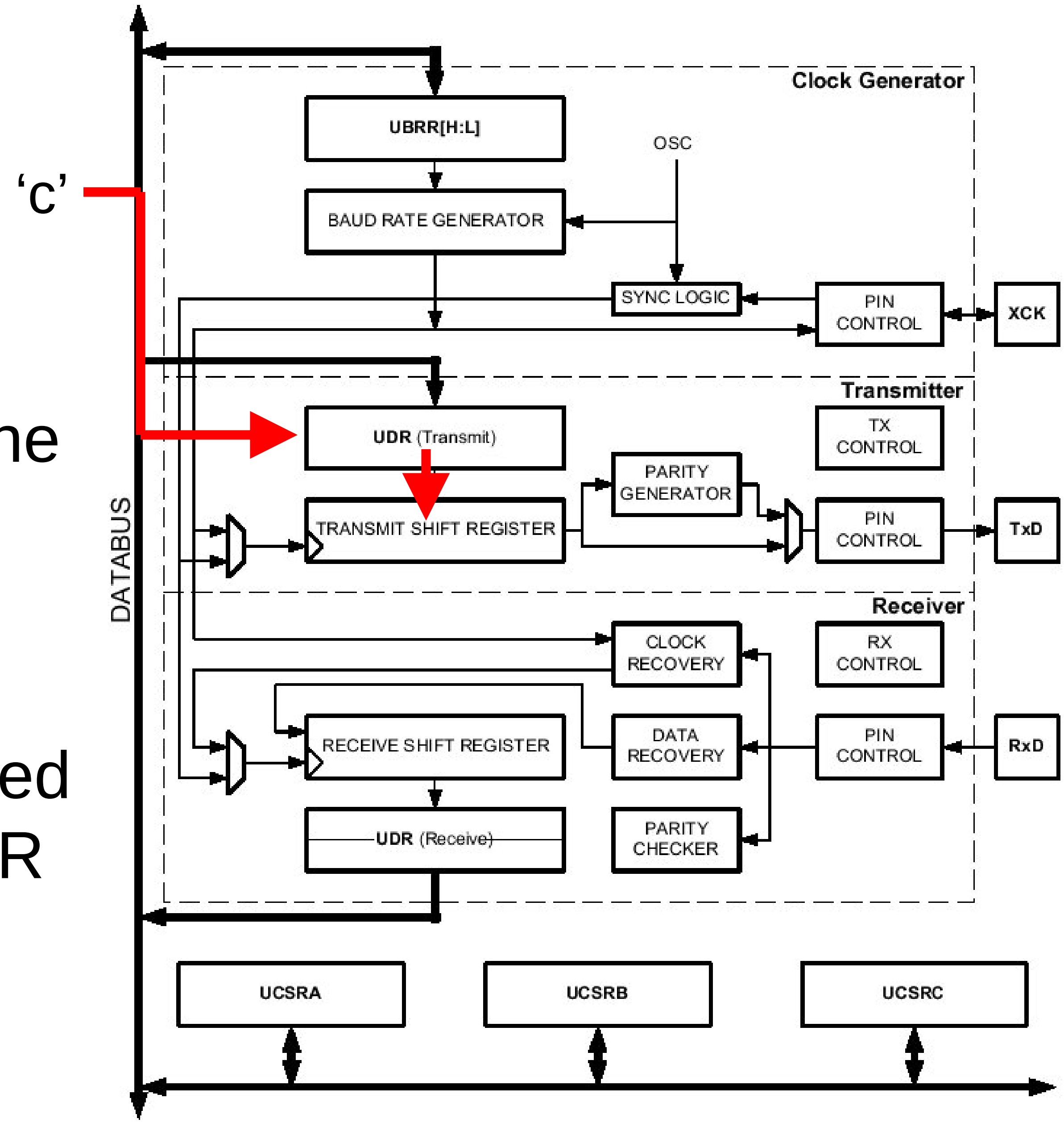
- 'c' placed onto the data bus and written to UDR



Mega8 UART

putchar('c')

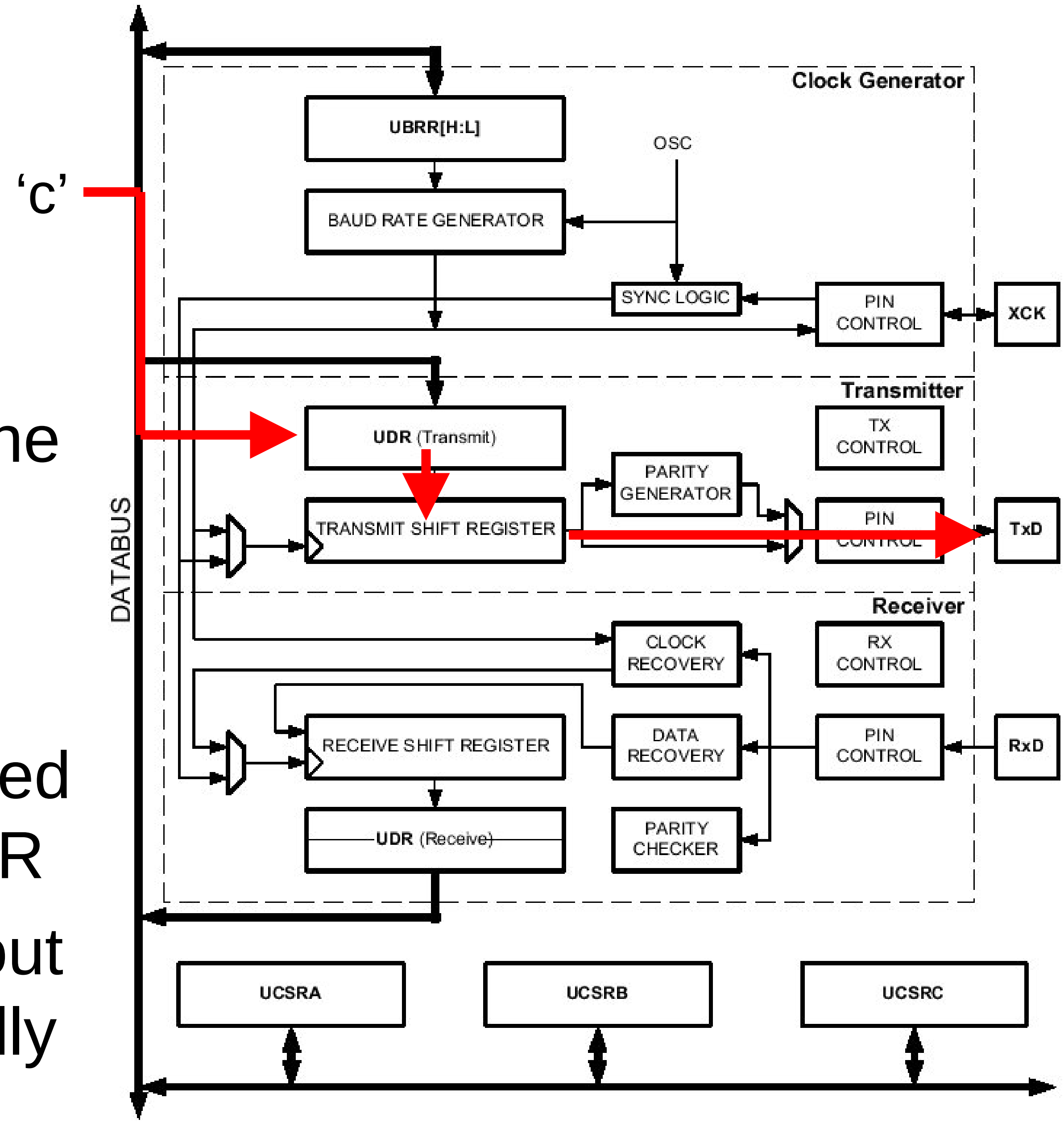
- 'c' placed onto the data bus and written to UDR
- When TSR is ready, 'c' is copied from UDR to TSR



Mega8 UART

putchar(‘c’)

- ‘c’ placed onto the data bus and written to UDR
- When TSR is ready, ‘c’ is copied from UDR to TSR
- TSR shifts bits out to pin sequentially



Mega8 UART C Interface

`printf()`: formatted output

`scanf()`: formatted input

See the LibC documentation or the AVR C textbook

I/O By Polling

Polling works great … but:

I/O By Polling

Polling works great … but:

- We have to guarantee that our other tasks do not take too long (otherwise, we may miss the event)
- Depending on the device, “too long” may be very short

Serial I/O by Polling

```
int c;
while(1) {
  if(kbhit()) {
     // A character is available for reading
     c = getchar();
     <do something with the character>
  }
  <do something else while waiting>
}
```

With this solution, how long can “something else” take?

I/O by Polling

In practice, we typically reserve this polling approach for situations in which:

- We know the event is coming very soon
- We must respond to the event very quickly

(both are measured in nano- to micro-seconds)

Receiving Serial Data

How can we allow the “something else” to take a longer period of time?

Receiving Serial Data

How can we allow the “something else” to take a longer period of time?

- The UART implements a 1-byte buffer
- Let’s create a larger buffer…

Receiving Serial Data

Creating a larger (circular) buffer. This will be a globally-defined data structure composed of:

- N-byte memory space:

```
volatile uint8_t buffer[BUF_SIZE];
```

- Integers that indicate the first element in the buffer and the number of elements:

```
volatile uint8_t front,  nchars;
```

Buffered Serial Data

Implementation:

- We will use an interrupt routine to transfer characters from the UART to the buffer as they become available

- Then, our main() function can remove the characters from the buffer

Interrupt Handler

```
// Called when the UART receives a byte
ISR(USART_RXC_vect) {
  // Handle the character in the UART buffer
  c = getchar();



  }
}
```

Interrupt Handler

```
// Called when the UART receives a byte
ISR(USART_RXC_vect) {
  // Handle the character in the UART buffer
  int c = getchar();

  if(nchars < BUF_SIZE) {
     buffer[(front+nchars)%BUF_SIZE] = c;
     nchars += 1;
  }
}
```

Reading Out Characters

```
// Called by a “main” program
// Get the next character from
  the circular buffer
int16_t get_next_character() {
  int16_t c;


  return(c);
}
```

Reading Out Characters

```
// Called by a “main” program
// Get the next character from the circular buffer
int get_next_character() {
   int c;
   if(nchars == 0)
       return(-1); // Error
   else {
       // Pull out the next character
       c = buffer[front];

       // Update the state of the buffer
       --nchars;
       front = (front + 1)%BUF_SIZE;
       return(c);
   }
}
```

An Updated main()

```
int c;
while(1) {
  do {
     c = get_next_character();
     if(c != -1)
          <do something with the character>
  }while(c != -1);

  <do something else while waiting>
}
```

Buffered Serial Data

This implementation captures the essence of what we want, but there are some subtle things that we must handle ….

Buffered Serial Data

Subtle issues:

- The reading side of the code must make sure that it does not allow the buffer to overflow
  - But at least we have BUF_SIZE times more time before this happens
- We also have a shared data problem …

The Shared Data Problem

- Two independent segments of code that could access the same data structure at arbitrary times
- In our case, get_next_character() could be interrupted while it is manipulating the buffer
  - This can be very bad

Solving the Shared Data Problem

- There are segments of code that we want to execute without being interrupted
- We call these code segments **critical sections**

Solving the Shared Data Problem

There are a variety of techniques that are available:

- Clever coding
- Hardware: test-and-set instruction
- Semaphores: software layer above test-and-set
- Disabling interrupts

Solving the Shared Data Problem

There are a variety of techniques that are available:

- Clever coding
- Hardware: test-and-set instruction
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- Disabling interrupts

Disabling Interrupts

- How can we modify get_next_character()?

- It is important that the critical section be as short as possible

Assume:

- serial_receive_enable(): enable interrupt flag
- serial_receive_disable(): clear (disable) interrupt flag

Modified get_next_character()

```
int get_next_character() {
   int c;
   serial_receive_disable();
   if(nchars == 0)
       serial_receive_enable();
       return(-1); // Error
   else {
       // Pull out the next character
       c = buffer[front];
       --nchars;
       front = (front + 1)%BUF_SIZE;
       serial_receive_enable();
       return(c);
   }
}
```

Initialization Details

```
main()
{
  serial0_init(9600);
  nchars = 0;
  front = 0;

  // Enable UART receive interrupt
  serial_receive_enable();

  // Enable global interrupts
  sei();
      :
```

Enable/Disable Serial Interrupt

One bit of UCSRB determines whether the serial receive interrupt is enabled or disabled. Here is the code:

```
inline void serial_receive_enable(void) {
  UCSRB |= _BV(RXCIE);  // Enable serial receive interrupt
}

inline void serial_receive_disable(void) {
  UCSRB &= ~_BV(RXCIE);  // Disable receive interrupt
}
```

Enabling/Disabling Interrupts

- Enabling/disabling interrupts allows us to ensure that a specific section of code (the critical section) cannot be interrupted
  - This allows for safe access to shared variables

- But: must not disable interrupts for a very long time

Alternative Solutions

- There is a clever change to the data structure that does not require enabling/disabling interrupts

- Also possible to put this buffer “behind” getchar() (and hence all other input functions)
  - See serial0_init() in OUlib to see how the hardware specific implementation is hooked into the general LIBC functions