Linux Power!

(From the perspective of a PMIC vendor)

Matti Vaittinen

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ROHM Semiconductors

Topics

Goal

What is PMIC

Regulator errors and notifications

Functional-safety helpers in regulator subsystem

What and Why is a PMIC?

PMIC drivers

- MFD and subdevices
- Regulators

Monitoring for abnormal conditions

- Severity levels and limit values
- Regulator errors and notifications
- Helpers and examples

Wrap it up

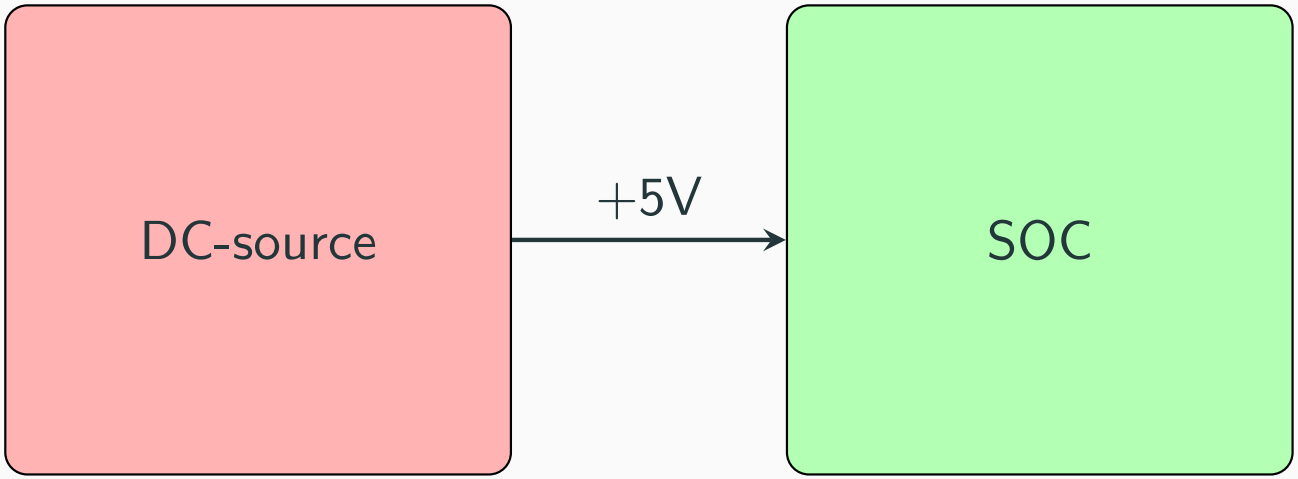
About Me

- Matti Vaittinen
- Kernel/Driver developer at ROHM Semiconductor
- Worked at Nokia BTS projects (networking, clock & sync) 2006 – 2018
- Currently mainly developing/maintaining upstream Linux device drivers for ROHM ICs

What and Why is a PMIC?

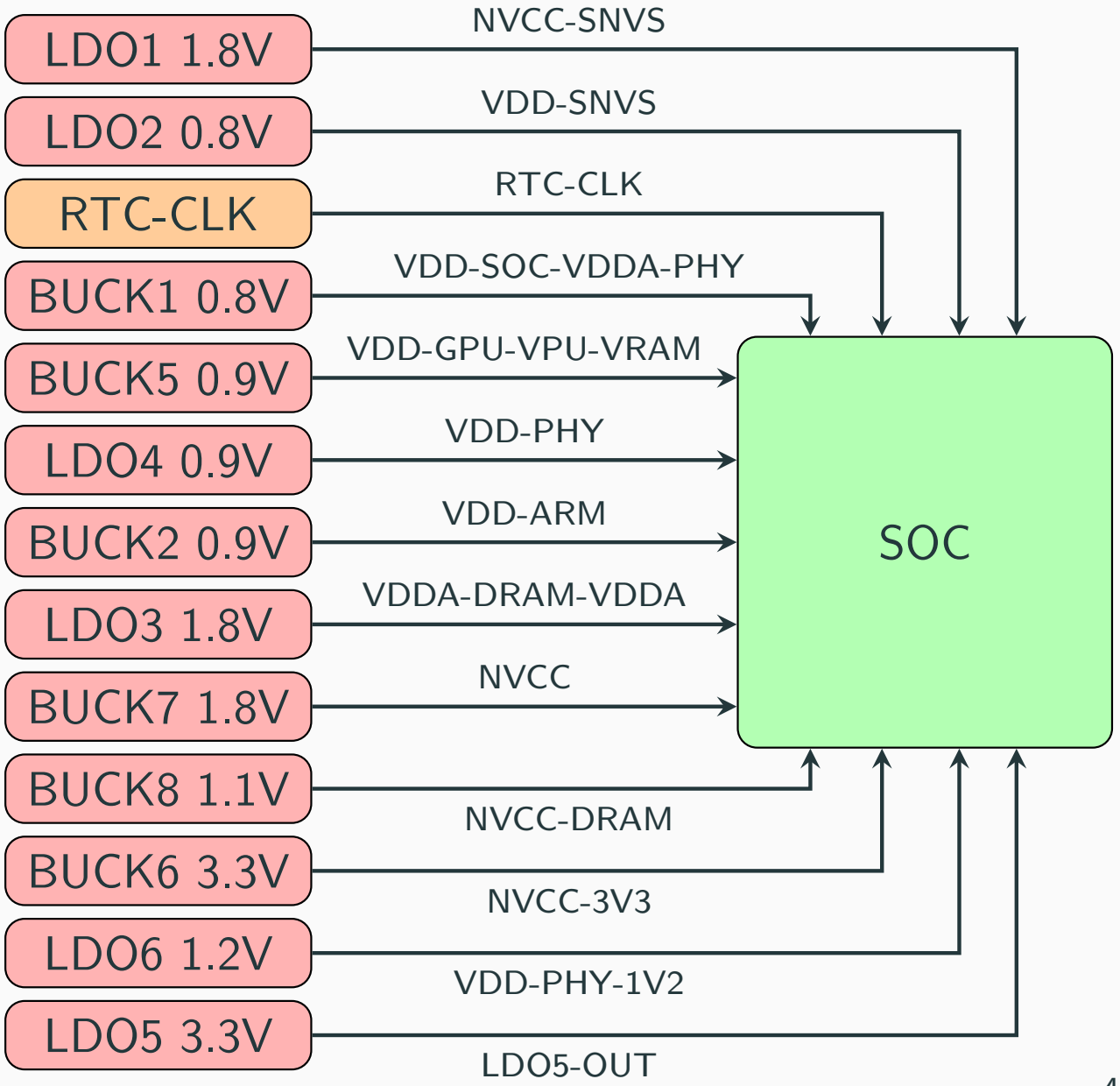
Powering a processor

- Processor and peripherals need power
- Can be as simple as a dummy DC power source with correct voltage



Powering a modern SOC 1/2

Modern SOCs can require multiple specific voltages



Powering a modern SOC 2/2

And specific timings...

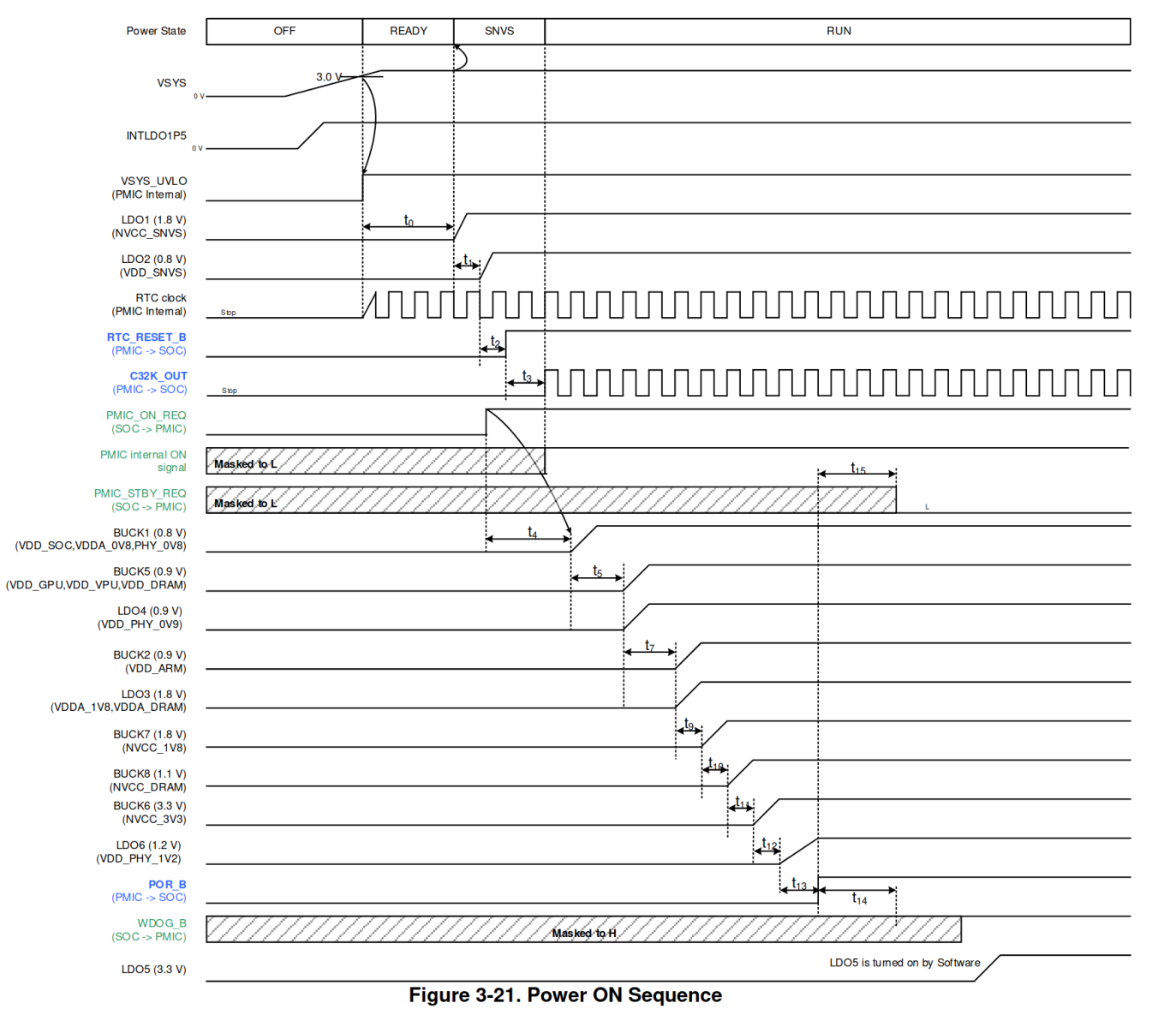


Figure 3-21. Power ON Sequence

More control...

Power savings by:

- Shutting down not needed devices
- Stand-by state(s)
- DVS (Dynamic Voltage Scaling)

Automated power on

Powering-on a system at given time...

- RTC

...Or by an event

- HALL sensor, ...

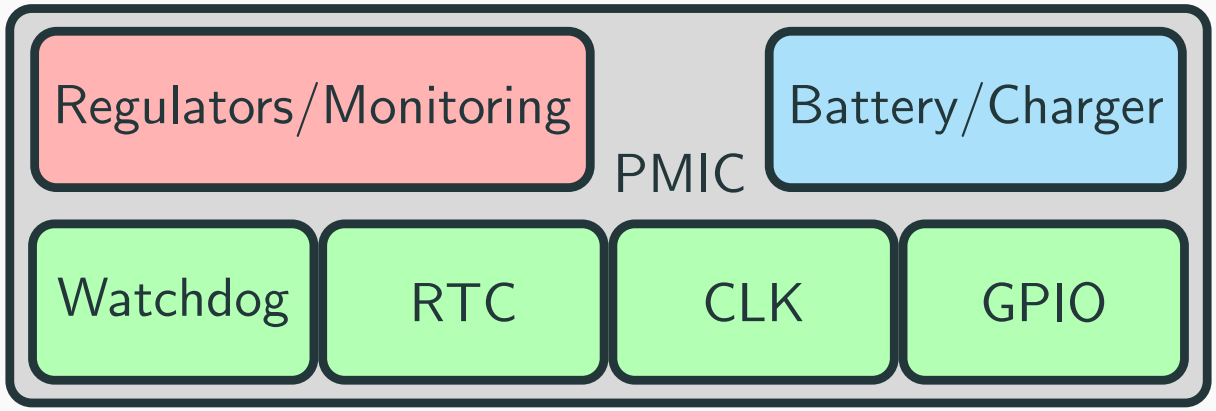
More requirements...

- Battery / charger
- Watchdog
- Functional-safety
  - Voltage monitoring
  - Current monitoring
  - Temperature monitoring

PMICs

PMIC - Power Management Integrated Circuit

- Multiple DC sources with specific start-up / shut-down sequence
- Voltage control
- Functional-safety
- Auxiliary blocks to support various needs



PMIC drivers

Multi Function Devices

Why? (I have 1 reason on mind, may be more)

Often MFD drivers

- **Regulator**
- RTC
- Power supply
- Watchdog
- GPIO
- CLK ...

Multi Function Devices

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- **Regulator**
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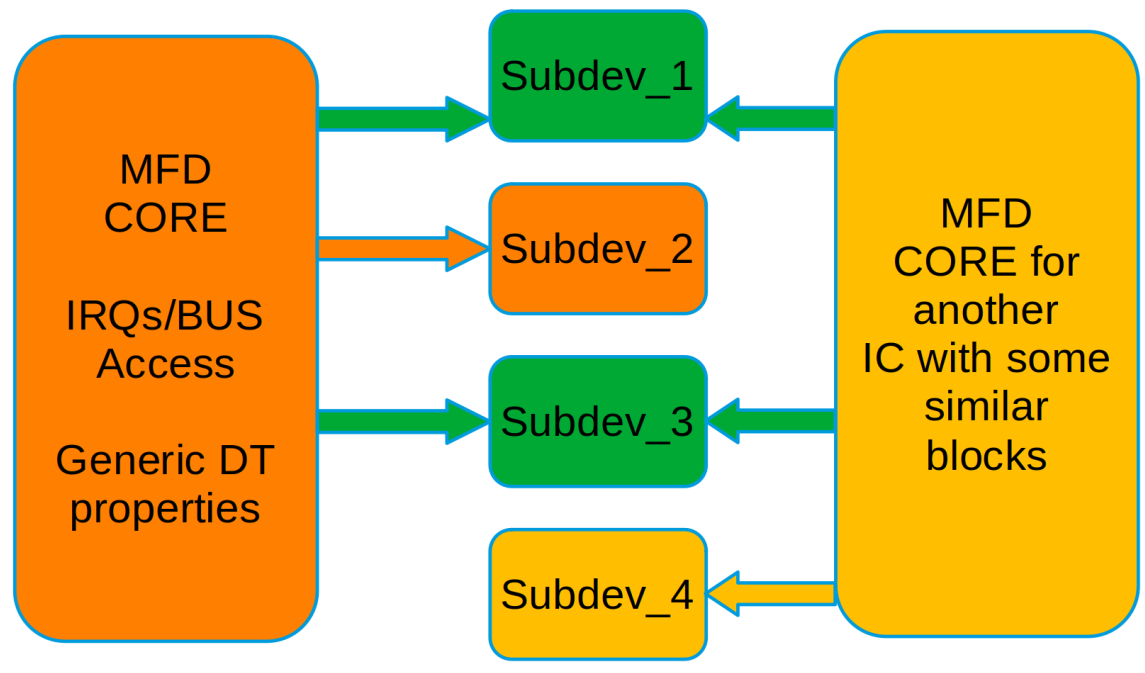
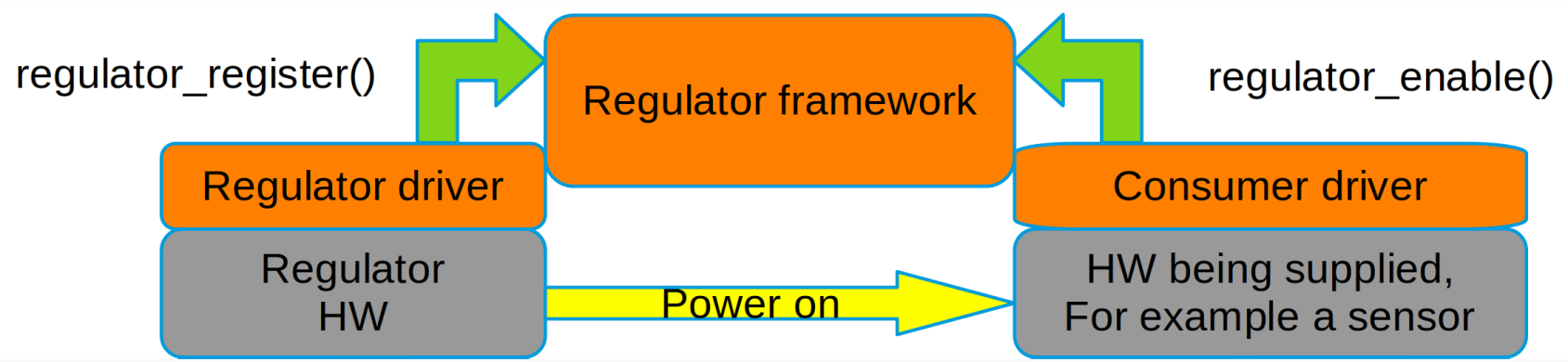
Allows re-use



Regulator (provider) and consumer

- Provider is driver interfacing the hardware. Eg, sits "below" the regulator framework. Between regulator framework and HW
- Consumer is driver who wishes to control the regulator using the regulator framework. Eg, sits "on top of" the regulator framework
- PMIC driver is the provider driver (usually just referred as a regulator driver)



Monitoring for abnormal conditions

Detecting undexpected

Linux has 3 severity categories

- **PROTECTION**
  - Unconditional shutdown by HW
- **ERROR**
  - Irrecoverable error, system not expected to be usable. Error handling by software.
- **WARNING** - NEW(ish)
  - Something is off-limit, system still usable but a recovery action should be taken to prevent escalation to errors

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Safety limits, devicetree

Property format:

- regulator-<event >-<severity >-<unit >= value

Over current:

- regulator-oc-protection-microamp
- regulator-oc-error-microamp
- regulator-oc-warn-microamp

Similar for over voltage (oc), under voltage (uv) and temperature (temp)

Values:

- 0 =>disable
- 1 =>enable
- other =>new limit

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Values:

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What if hardware does not support given limit?

Callbacks for configuring the limits

```
struct regulator_ops {
        // snip
        int (*set_over_current_protection)(struct regulator_dev *,
                int lim_uA, int severity, bool enable);
        int (*set_over_voltage_protection)(struct regulator_dev *,
                int lim_uV, int severity, bool enable);
        int (*set_under_voltage_protection)(struct regulator_dev *,
                int lim_uV, int severity, bool enable);
        int (*set_thermal_protection)(struct regulator_dev *, int lim,
                int severity, bool enable);
};

struct regulator_desc {
        // snip
        const struct regulator_ops *ops;
};

struct regulator_dev *devm_regulator_register(struct device *dev,
                        const struct regulator_desc *regulator_desc,
                        const struct regulator_config *config);
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Simplified example

```
static int bd9576_set_ocp(struct regulator_dev *rdev, int lim_uA,
                          int severity, bool enable)
{
        ...

        /* Return -EINVAL for unsupported configurations */
        if ((lim_uA && !enable) || (!lim_uA && enable))
                return -EINVAL;

        /*
         * Select the correct register and appropriate register-value
         * conversion for given severity and limit..
         */
        if (severity == REGULATOR_SEVERITY_PROT) {
                ...
        } else {
                ...
        }

        /* Write configuration to registers */
        return bd9576_set_limit(range, num_ranges, d->regmap,
                                reg, mask, Vfet);
}
```

Informing the unexpected

Two types of information

- ERRORs
- NOTIFICATIONs

- **ERROR**
  - set by provider
  - queried (polled) by consumer
  - regulator_get_error_flags()
- **NOTIFICATION**
  - sent by provider (usually) from interrupt
  - no polling needed
  - regulator_register_notifier()
  - can send also other events

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Regulator error flags

```
#define REGULATOR_ERROR_UNDER_VOLTAGE
#define REGULATOR_ERROR_OVER_CURRENT
#define REGULATOR_ERROR_REGULATION_OUT
#define REGULATOR_ERROR_FAIL
#define REGULATOR_ERROR_OVER_TEMP
#define REGULATOR_ERROR_UNDER_VOLTAGE_WARN
#define REGULATOR_ERROR_OVER_CURRENT_WARN
#define REGULATOR_ERROR_OVER_VOLTAGE_WARN
#define REGULATOR_ERROR_OVER_TEMP_WARN
```

include/linux/regulator/consumer.h

Regulator notifications

```
#define REGULATOR_EVENT_UNDER_VOLTAGE
#define REGULATOR_EVENT_OVER_CURRENT
#define REGULATOR_EVENT_REGULATION_OUT
#define REGULATOR_EVENT_FAIL
#define REGULATOR_EVENT_OVER_TEMP
 ...
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#define REGULATOR_EVENT_OVER_CURRENT_WARN
#define REGULATOR_EVENT_OVER_VOLTAGE_WARN
#define REGULATOR_EVENT_OVER_TEMP_WARN
#define REGULATOR_EVENT_WARN_MASK
```

include/linux/regulator/consumer.h

Notifications

Usually IRQ backed

1. PMIC detects error and generates IRQ
2. IRQ handler sends notification
3. Regulator consumer action is executed

In some (many) cases IRQ is held active for whole duration of error

- Maybe because these IRQs are considered as a last thing?
- Maybe because there is need to ensure IRQ is not missed?
- Does not play well with all systems

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Event IRQ helper

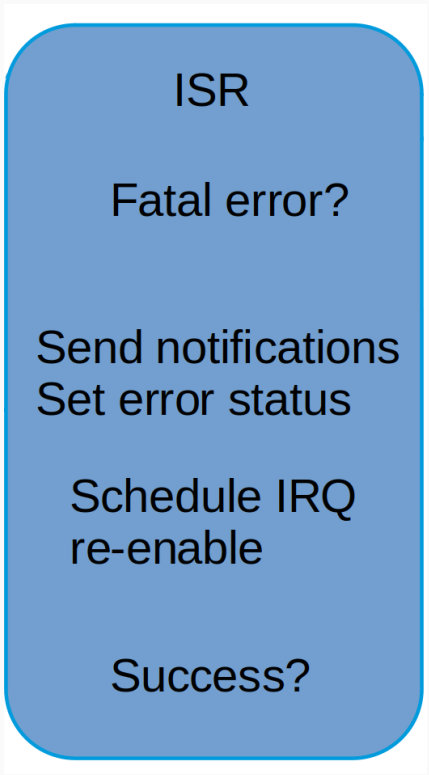
A helper provided for IRQ handling and sending the notification

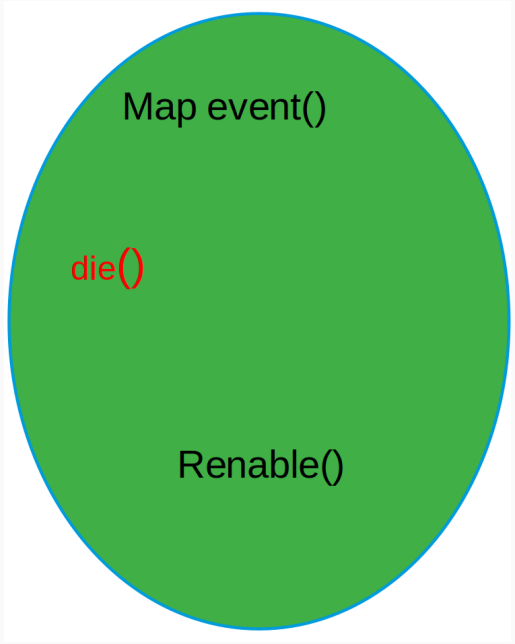
- Supports keeping IRQ disabled for a period of time
- Supports forcibly shutting down the system if accesing the PMIC fails

```
void *regulator_irq_helper(struct device *dev,
                           const struct regulator_irq_desc *d, int irq,
                           int irq_flags, int common_errs,
                           int *per_rdev_errs, struct regulator_dev **rdev,
                           int rdev_amount);
```

Helper break-out

events helper action driver





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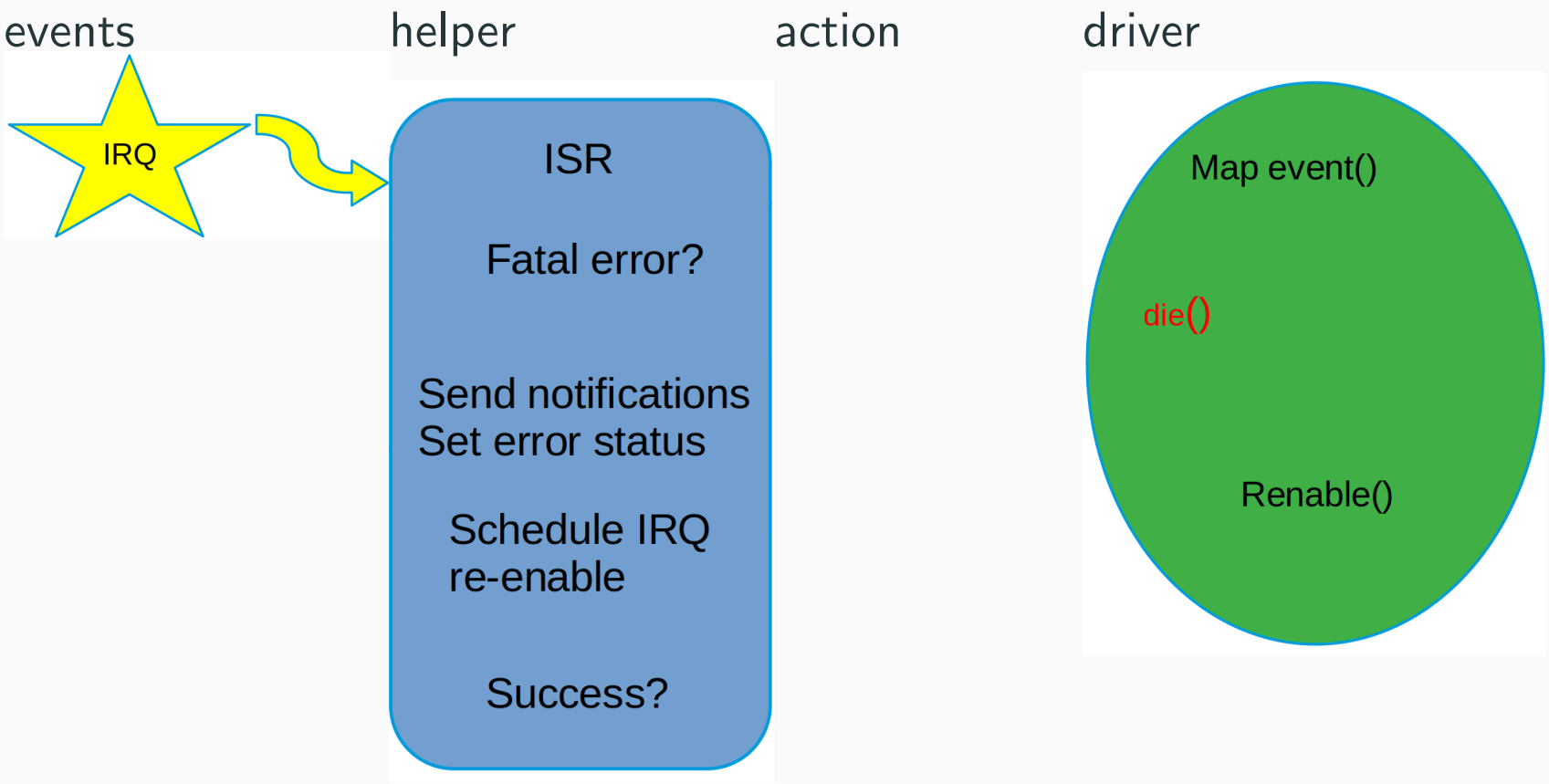

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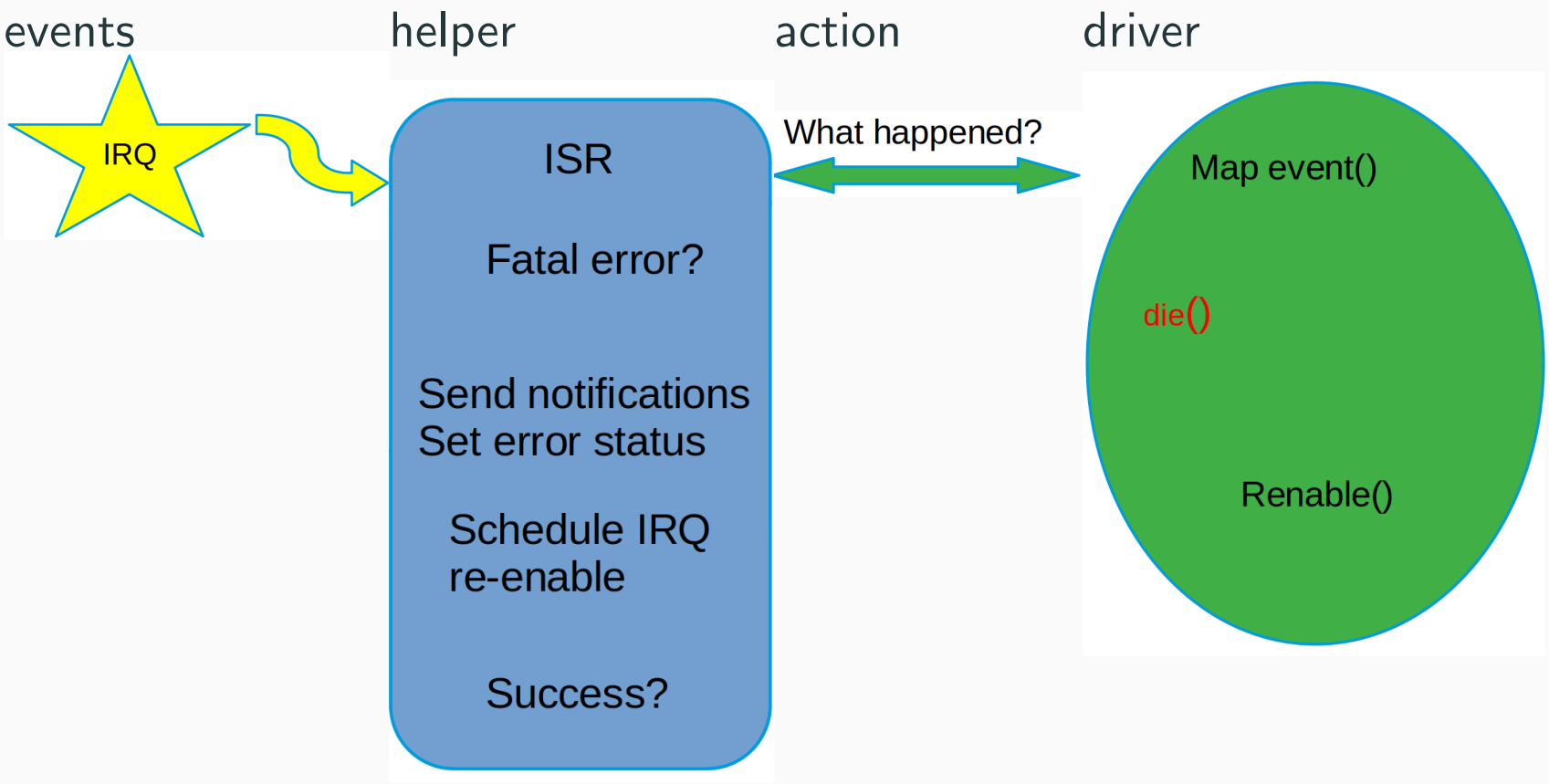

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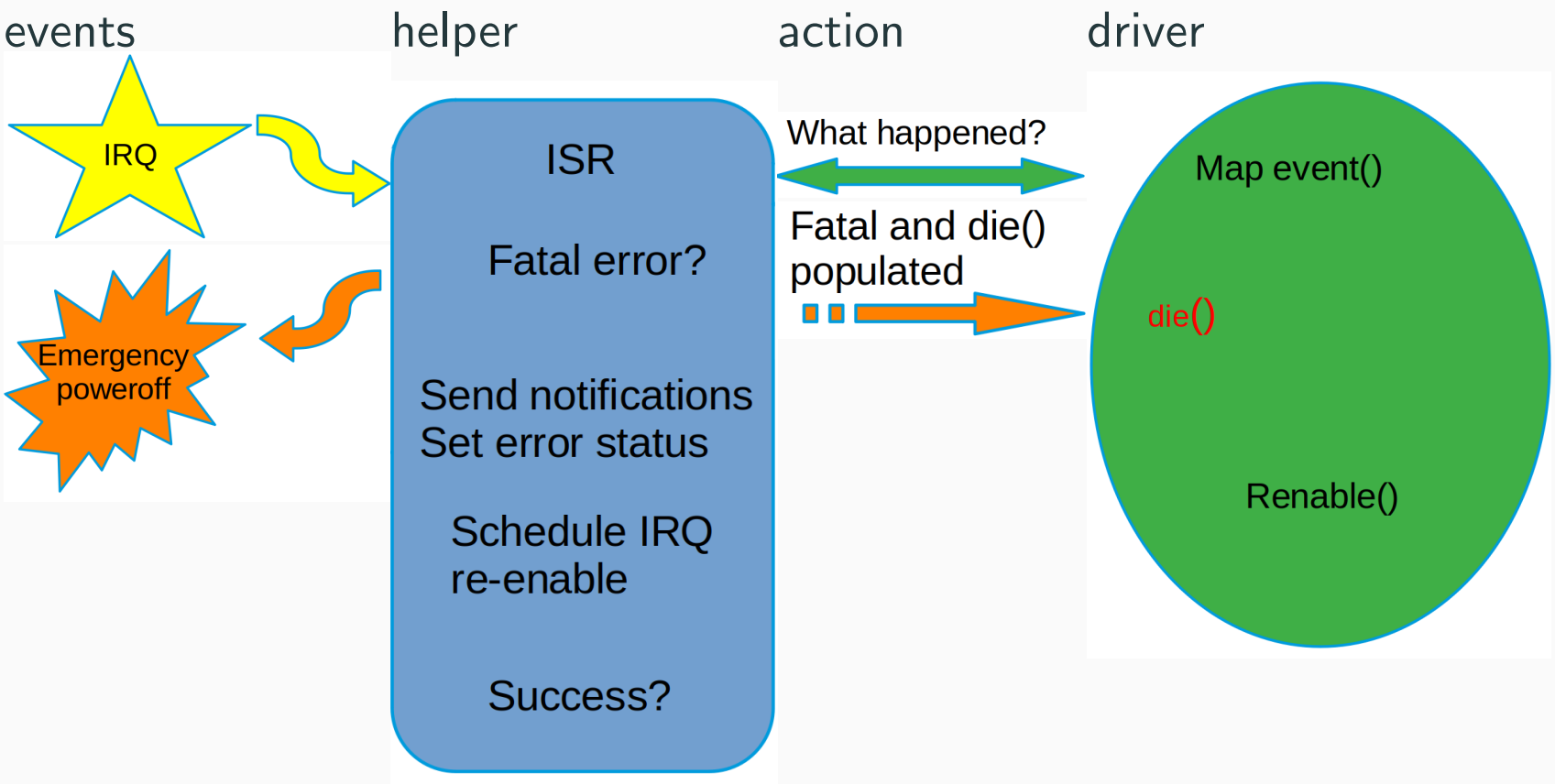

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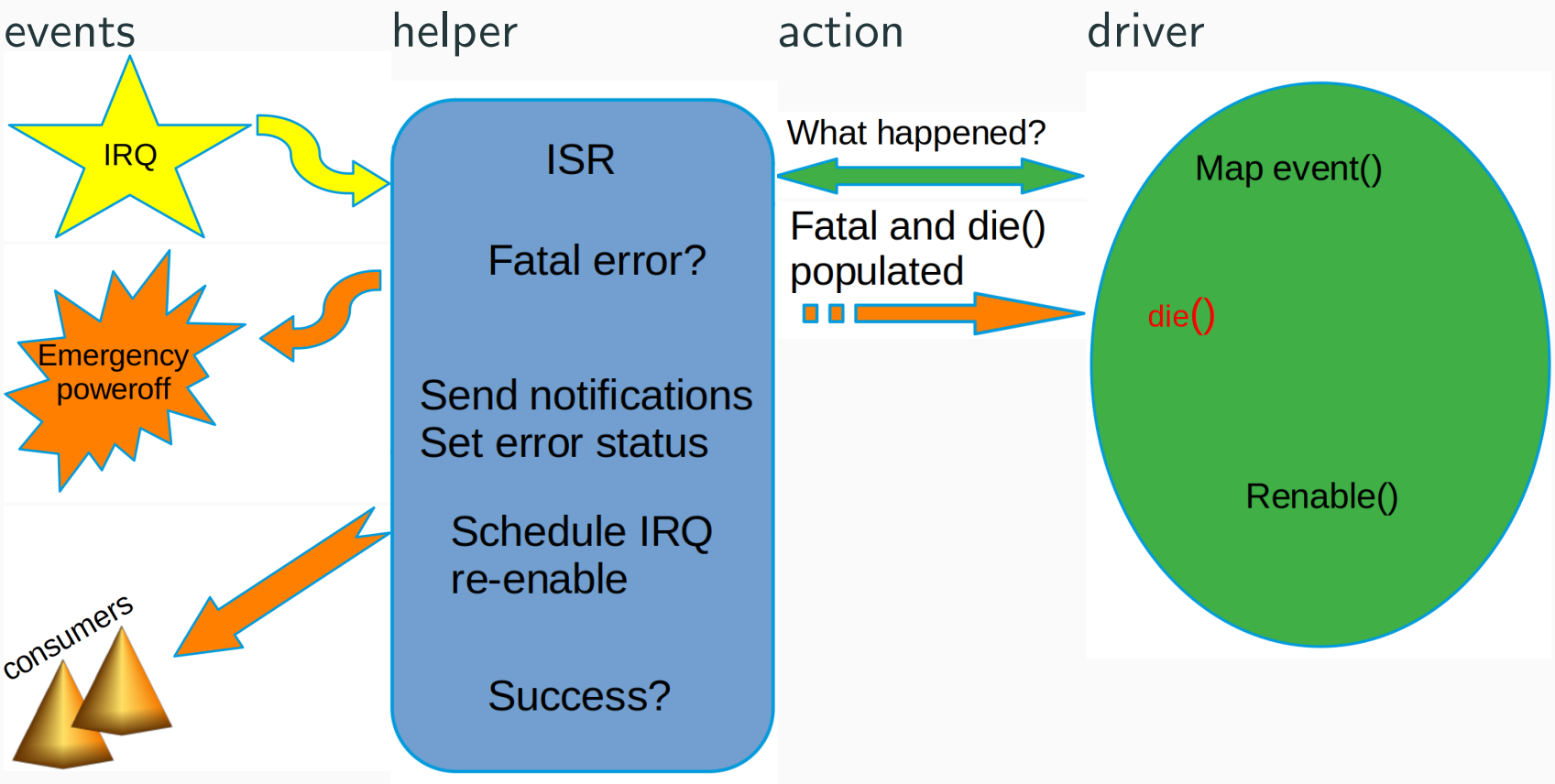

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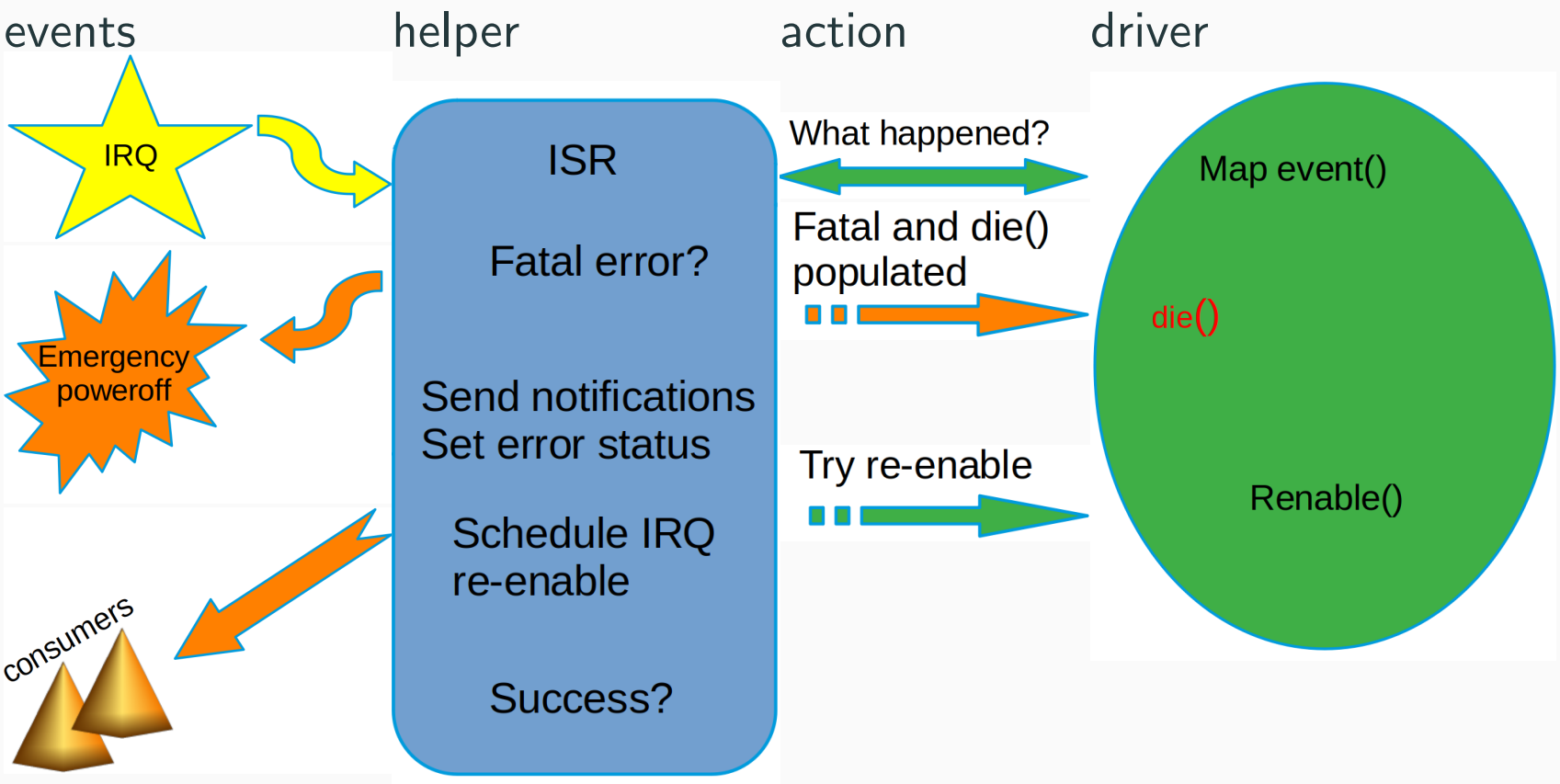

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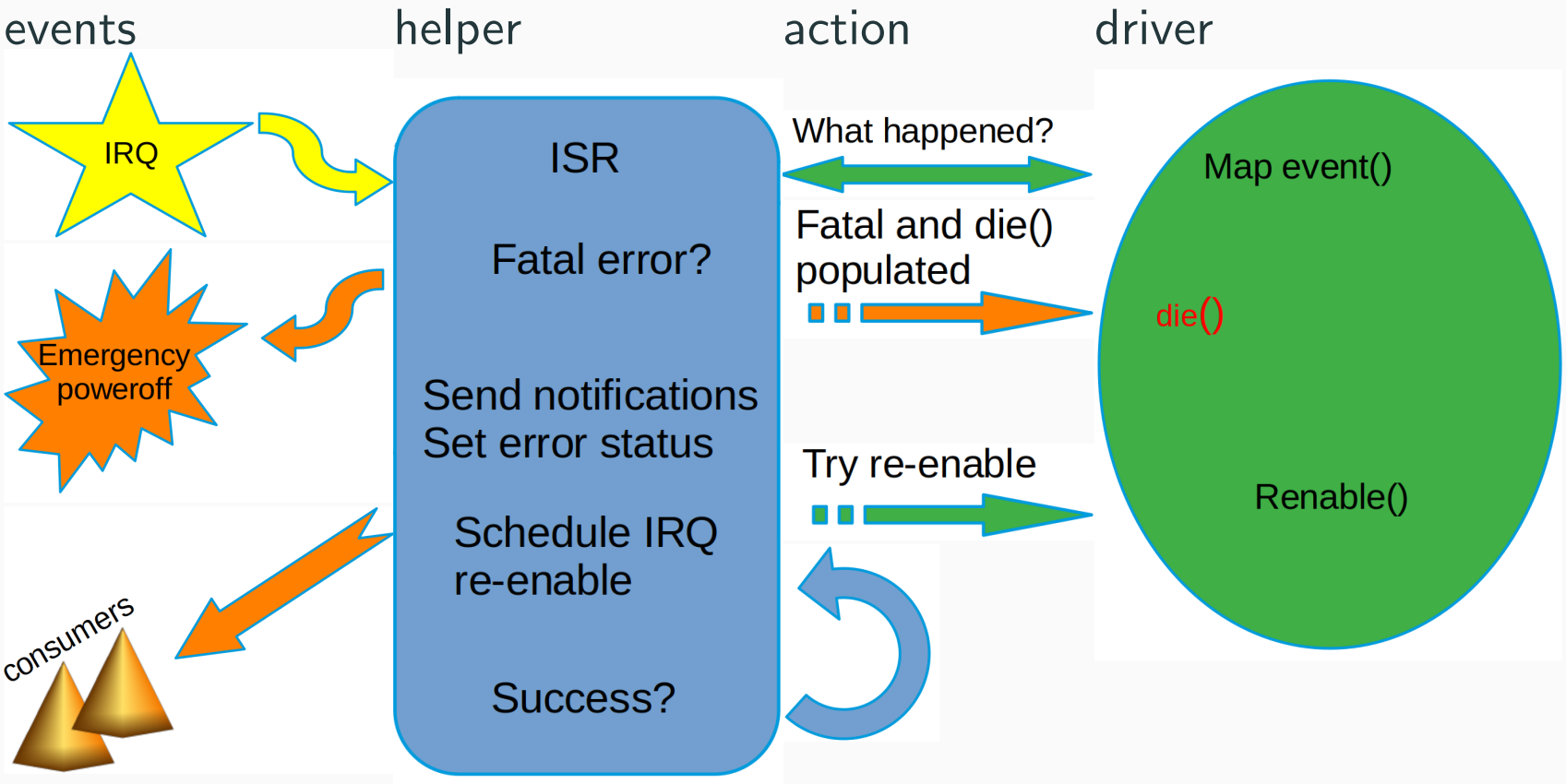

Helper configuration

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struct regulator_irq_desc {
        const char *name;
        int fatal_cnt;

        int reread_ms;
        int irq_off_ms;

        bool skip_off;
        bool high_prio;

        void *data;
        int (*die)(struct regulator_irq_data *rid);
        int (*map_event)(int irq, struct regulator_irq_data *rid,
             unsigned long *dev_mask);
        int (*renable)(struct regulator_irq_data *rid);
};

void *regulator_irq_helper(struct device *dev,
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(or a devm-variant)

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Event mapping

```
int (*map_event)(int irq, struct regulator_irq_data *rid,
                 unsigned long *dev_mask);

struct regulator_irq_data {
        struct regulator_err_state *states;
        int num_states;
        void *data;
        long opaque;
};

struct regulator_err_state {
        struct regulator_dev *rdev;
        unsigned long notifs;
        unsigned long errors;
        int possible_errs;
};

int (*renable)(struct regulator_irq_data *rid);

int regulator_irq_map_event_simple(int irq,
                        struct regulator_irq_data *rid,
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Event mapping example

```
static int bd9576_ovd_handler(int irq, struct regulator_irq_data *rid,
                              unsigned long *dev_mask)
{
        ret = regmap_read(d->regmap, BD957X_REG_INT_OVD_STAT, &val);
        if (ret)
                return REGULATOR_FAILED_RETRY;

        rid->opaque = val & OVD_IRQ_VALID_MASK;
        *dev_mask = 0;

        if (!(val & OVD_IRQ_VALID_MASK))
                return 0;

        *dev_mask = val & BD9576_xVD_IRQ_MASK_VOUT1TO4;

        for_each_set_bit(i, dev_mask, 4) {
                stat  = &rid->states[i];

                stat->notifs     = rdata->ovd_notif;
                stat->errors     = rdata->ovd_err;
        }

        return 0;
}
```

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        for_each_set_bit(i, dev_mask, 4) {
                stat  = &rid->states[i];

                stat->notifs     = rdata->ovd_notif;
                stat->errors     = rdata->ovd_err;
        }

        return 0;
}
```

Event mapping example

```
static int bd9576_ovd_handler(int irq, struct regulator_irq_data *rid,
                              unsigned long *dev_mask)
{
        ret = regmap_read(d->regmap, BD957X_REG_INT_OVD_STAT, &val);
        if (ret)
                return REGULATOR_FAILED_RETRY;

        rid->opaque = val & OVD_IRQ_VALID_MASK;
        *dev_mask = 0;

        if (!(val & OVD_IRQ_VALID_MASK))
                return 0;

        *dev_mask = val & BD9576_xVD_IRQ_MASK_VOUT1TO4;

        for_each_set_bit(i, dev_mask, 4) {
                stat  = &rid->states[i];

                stat->notifs     = rdata->ovd_notif;
                stat->errors     = rdata->ovd_err;
        }

        return 0;
}
```

Helper registration 1/2

Fill the helper configuration

```
static const struct regulator_irq_desc bd9576_notif_ovd = {
        .name = "bd9576-ovd",
        .irq_off_ms = 1000,
        .map_event = bd9576_ovd_handler,
        .renable = bd9576_ovd_renable,
        .data = &bd957x_regulators,
};
```

Helper registration 1/2

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        .data = &bd957x_regulators,
};
```

Helper registration 2/2

Create an array of regulators this IRQ may concern

```
struct regulator_dev *rdevs[BD9576_NUM_REGULATORS];

for (i = 0; i < num_rdev; i++) {
        struct bd957x_regulator_data *r = &ic_data->regulator_data[i];
        const struct regulator_desc *desc = &r->desc;

        r->rdev = devm_regulator_register(&pdev->dev, desc, &config);

        rdevs[i] = r->rdev;
        if (i < BD957X_VOUTS1)
                ovd_devs[i] = r->rdev;
}
```

Fill possible errors this IRQ may indicate and register the helper

```
int ovd_errs = REGULATOR_ERROR_OVER_VOLTAGE_WARN |
        REGULATOR_ERROR_REGULATION_OUT;

ret = devm_regulator_irq_helper(&pdev->dev, &bd9576_notif_ovd,
                                irq, 0, ovd_errs, NULL,
                                &ovd_devs[0],
                                BD9576_NUM_OVD_REGULATORS);
```

Helper registration 2/2

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                                BD9576_NUM_OVD_REGULATORS);
```

Wrap it up

Summary

- Powering up a modern SOC is not simple
- PMIC is an IC trying to integrate powering related features into single chip
- Many PMICs include functional-safety features
- There is some existing support for indicating abnormal events

No answers guaranteed

Questions?

No answers guaranteed

Thank You for listening!

(or time to wake up) :)

Extras

How to handle notifications?

```
typedef int (*notifier_fn_t)(struct notifier_block *nb,
                        unsigned long action, void *data);

struct notifier_block {
        notifier_fn_t notifier_call;
        struct notifier_block __rcu *next;
        int priority;
};

/**
 * regulator_register_notifier – register regulator event notifier
 * @regulator: regulator source
 * @nb: notifier block
 *
 * Register notifier block to receive regulator events.
 */
int regulator_register_notifier(struct regulator *regulator,
                                struct notifier_block *nb)
```