使用错误代码替换 `OS-2026/app-helloworld/workdir/unikraft/lib/ukallocbbuddy/bbuddy``.c:495-565` 处的原 `bbuddy_pfree()` 函数

启动 QEMU 并开启 gdb 远程调试端口

```
@ywenzhe → /workspaces/OS-2026/app-helloworld (main) $ qemu-system-aarch64 -kernel workdir/
build/helloworld_qemu-arm64 -nographic -machine virt -cpu cortex-a57 -s -S
```

使用 gdb-multiarch 连接 QEMU

```
@ywenzhe → /workspaces/OS-2026/app-helloworld (main) $ gdb-multiarch workdir/build/helloworld_qemu
-arm64.dbg --eval-command="target remote :1234"
GNU gdb (Ubuntu 15.0.50.20240403-0ubuntu1) 15.0.50.20240403-git
Copyright (C) 2024 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.
Type "show copying" and "show warranty" for details.
This GDB was configured as "x86_64-linux-gnu".
Type "show configuration" for configuration details.
For bug reporting instructions, please see:
<https://www.gnu.org/software/gdb/bugs/>.
Find the GDB manual and other documentation resources online at:
    <http://www.gnu.org/software/gdb/documentation/>.

For help, type "help".
Type "apropos word" to search for commands related to "word"...
Reading symbols from workdir/build/helloworld_qemu-arm64.dbg...
Remote debugging using :1234
0x0000000040000000 in ?? ()
(gdb)
```

在 `bbuddy_pfree` 函数处设置断点并开始调试

```
@ywenzhe → /workspaces/OS-2026/app-helloworld (main) $ gdb-multiarch workdir/build/helloworld_qemu
-arm64.dbg --eval-command="target remote :1234"
lloc.c, line 209.
(gdb) c
Continuing.

Breakpoint 2, uk_free_ifpages (a=0x40010000, ptr=0x40192020, small=0x4011acc4 <uk_free_ifpages>)
    at /workspaces/OS-2026/app-helloworld/workdir/unikraft/lib/ukalloc/alloc.c:209
209          UK_ASSERT(a);
(gdb) set small=0
(gdb) b bbuddy_pfree
Breakpoint 3 at 0x4011c918: file /workspaces/OS-2026/app-helloworld/workdir/unikraft/lib/ukallocbb
uddy/bbuddy.c, line 502.
(gdb) c
Continuing.

Breakpoint 3, bbuddy_pfree (a=0x40010000, obj=0x40192000, num_pages=2)
    at /workspaces/OS-2026/app-helloworld/workdir/unikraft/lib/ukallocbbuddy/bbuddy.c:502
warning: Source file is more recent than executable.
502          UK_ASSERT(a != NULL);
(gdb)
```

由调试结果发现两处错误：

1.类型不匹配(第 66 行)

错误代码：

```c
1  int nr_page_left = 1UL << order;
```

问题描述：使用 `int` 类型存储 `unsigned long` 类型的位移运算结果。当 `order` 较大时，`1UL << order` 可能超出 `int` 的表示范围,导致溢出或负数。

正确代码:

```c
1  unsigned long nr_page_left = 1UL << order;
```

修正说明: 将变量类型改为 `unsigned long` ,与右侧表达式类型匹配,避免潜在的溢出问题。

2.未正确实现伙伴算法

问题描述: 回收时未进行相邻页合并，导致所有页面被放入 order 0，长期运行会产生大量的内存碎片。

修正说明: 恢复原来的伙伴算法实现