

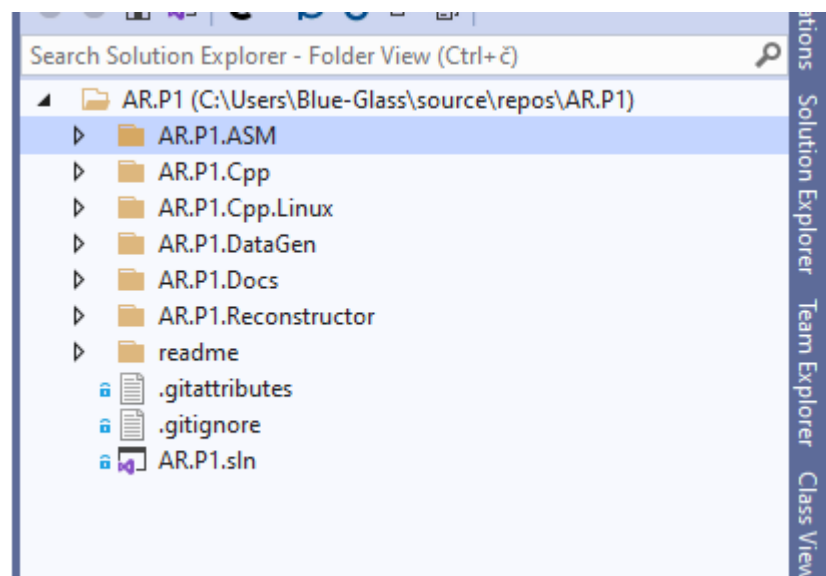
# Dokumentacija

## Uvod

Rešenje ima za cilj implementaciju Fast Fourier Transform (FFT) algoritma. Konkretno, Cooley Tukey<sup>i</sup> varijantu FFT.

Rešenje se sastoji od sledećih projekata, gde ime svakog sadrži prefiks „AR.P1“

1. ASM – NASM AMD x64 Linux implementacija  
Kompajluje se pomoću GCC-a, koristi neke minimalne funkcije iz GNU C biblioteke i koristi Linux sistemske pozive.
2. Cpp – C++ implementacija, AMD x64 Windows
3. Cpp.Linux – C++ implementacija, AMD x64 Linux
4. DataGen - .NET CLI alat  
Generator ulaznih .WAV fajlova za rad prethodnih implementacija
5. Docs – Dokumentacija rešenja
6. Reconstructor - .NET konzolna aplikacija  
Za konverziju binarnog izlaza implementacija u čitljivi CSV fajl

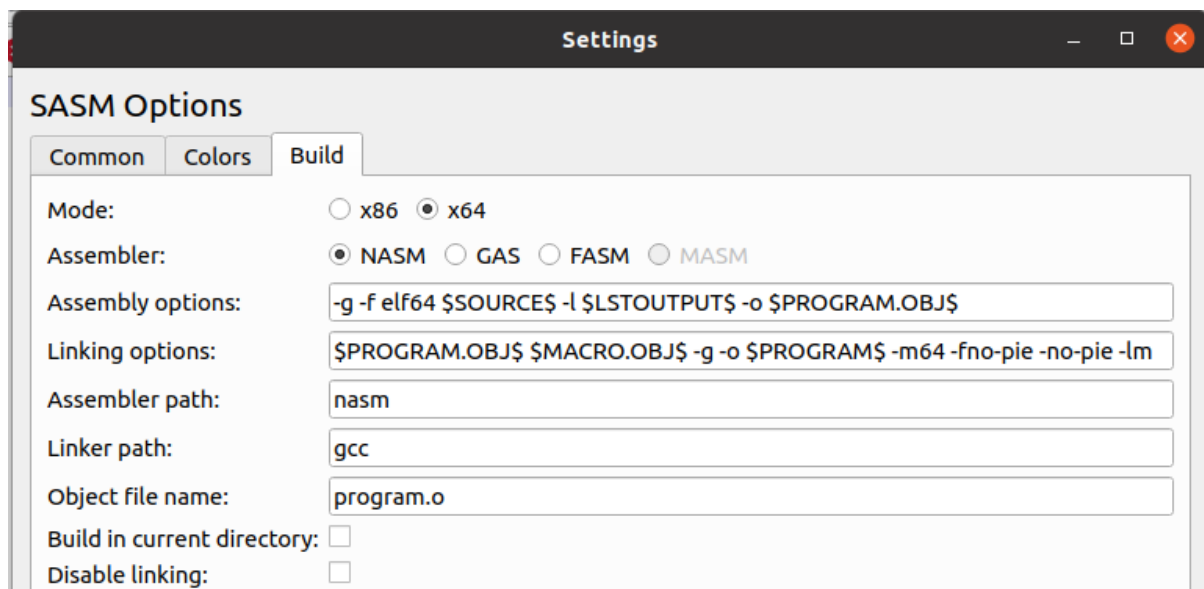


Prikaz 1

## Kompajlovanje

Svi projekti, sem ASM projekta, se mogu kompajlovati direktno iz MS Visual Studio alata.

Za kompajlovanje ASM projekta, bez ikakvih modifikacija, sugerisano je da se koristi SASM<sup>ii</sup> grafičko okruženje za kompajlovanje pomoću GCC kompajlera. Ispod je priloženo podešavanje koje je korišteno za kompajlovanje pri razvoju projekta.



Prikaz 2

## Poređenje po brzini

Obzirom na specifičnosti implementacije, poređenje C++ i assembly implementacija se vrši između ASM projekta i Cpp.Linux projekta (zbog istog kompajlera, OS podrške, ...).

Cpp.Linux

Bez kompajlerskih optimizacija

```
real    0m41.675s
user    0m37.959s
sys     0m2.869s
```

Prikaz 3

-Os optimizacija veličine koda

```
real    0m23.982s
user    0m13.891s
sys     0m5.287s
```

Prikaz 4

-O2 optimizacije

```
real    0m25.410s
user    0m9.908s
sys     0m6.795s
```

Prikaz 5

-O3 maksimalne optimizacije

```
real    0m22.853s
user    0m9.927s
sys     0m6.057s
```

Prikaz 6

ASM

Osnovna implementacija

```
real    0m38.699s
user    0m26.271s
sys     0m12.018s
```

Prikaz 7

RSWS - Optimizacija konverzije ulaznog fajla

```
real    0m29.449s
user    0m25.701s
sys     0m2.935s
```

Prikaz 8

SIMD - SIMD optimizacije algoritma, bez optimizacija konverzije

```
real    0m27.554s
user    0m13.934s
sys     0m12.837s
```

Prikaz 9

SIMD RSWS - optimizacije algoritma, sa optimizacijama konverzije

```
real    0m15.427s
user    0m12.756s
sys     0m2.533s
```

Prikaz 10

Za dobavljanje podataka, korišten je *bash shell* i *time* CLI alat, upotrebom sledećih komandi:

```
time ( for i in {1..1000}; do ~/AR.P1.Cpp.Linux.out ~/output.wav; done )
time ( for i in {1..1000}; do ~/SASMprog_simd_rws.exe ~/output.wav; done )
```

Sekvencijalno, programi obe implementacije su pozvani 1000 puta kako bi se efekti standardne devijacije i uticaja faktora virtuelne mašine (na kojoj su programi izvršavani) na vremena izvršavanja smanjili.

Ispod je dat tabelarni prikaz vremena izvršavanja, u sekundama, sa podelom ukupnog vremena izvršavanja (real) na vreme koje CPU provede u user mode-u (user) i vremenom koje provede u kernel modu (sys).

[s]	Cpp.Linux				ASM			
	No opts	-Os	-O2	-O3	No opts	RSWS	SIMD	SIMD, RSWS
real	41.675	23.982	25.410	22.853	38.699	29.449	27.554	15.427
user	37.959	13.891	9.908	9.927	26.271	25.701	13.934	12.756
sys	2.869	5.287	6.795	6.057	12.018	2.935	12.837	2.533

Prikaz 11

Ispod je dat prikaz ubzranja rada pri različitim optimizacijama u okviru Cpp.Linux projekta.

% = [vreme nivoa optimizacije] / [No opts]	-Os	-O2	-O3
real	57.55	60.97	54.84
user	36.59	26.10	26.15
sys	184.28	236.84	211.12

Prikaz 12

Ispod je dat prikaz ubzranja rada pri različitim optimizacijama u okviru ASM projekta.

% = [vreme nivoa optimizacije] / [No opts]	RSWS	SIMD	SIMD, RSWS
real	76.10	71.20	39.86
user	97.83	53.04	48.56
sys	24.42	106.81	21.08

Prikaz 13

Ispod je dat prikaz međusobnih poređenja, između Cpp.Linux i ASM projekata.

% = [% ASM vreme] / [% Cpp.Linux vreme]	No opts vs No opts	RSWS vs -Os	SIMD vs -O2	SIMD, RSWS vs -O3
real	92.86	122.80	108.44	67.51
user	69.21	185.02	140.63	128.50
sys	418.89	55.51	188.92	41.82

Prikaz 14

Pri čemu, manje vrednosti procenata indikuju brže izvršavanje prvog od dva slučaja koja se porede. Npr. poređenjem SIMD, RSWS i -O3 vidimo da SIMD, RSWS varijanti treba 67% vremena -O3 varijante za izvršavanje, odnosno brža je za  $1 - 67.51\% = 32.49\%$ .

Pri uzimanju u obzir ovih cifara, treba napomenuti da Cpp.Linux projekat ne koristi AVX instrukcije za optimizaciju glavnog dela FFT algoritma, ali koristi AVX instrukcije za učitavanje i obradu .WAV fajla. Stoga, ako bi se iste AVX instrukcije upotrebile u Cpp.Linux projektu, moguće je videti drugačije rezultate.

## Poređenje po broju instrukcija i samim instrukcijama

Upotrebom callgrind alata iz valgrind skupa alata, generisani su dump-ovi koji su upotrebljeni u svrhe poređenja broja instrukcija i koda izvršnog koda svih varijanti. Dump-ovi su generisani komandom:

```
valgrind --tool=callgrind ./SASMprog_*varijanta*.exe ./output.wav
```

Ispod je priložena tabela sa procenjenim brojem CPU ciklusa pri izvršavanju različitih varijanti izvršnog koda.

### Cpp.Linux

	Procenjeni broj CPU ciklusa
No opts	161 995 441
-Os	64 393 178
-O2	56 950 372
-O3	54 740 209

### ASM

	Procenjeni broj CPU ciklusa
No opts	93 716 528
RSWS	92 859 398
SIMD	85 811 196
SIMD, RSWS	84 954 059

Interesantno je da -O2 nivo optimizacije rezultuje u relativno velikom procenjenom broju CPU ciklusa, iako je izvršavanje brže u odnosu na neke varijante.

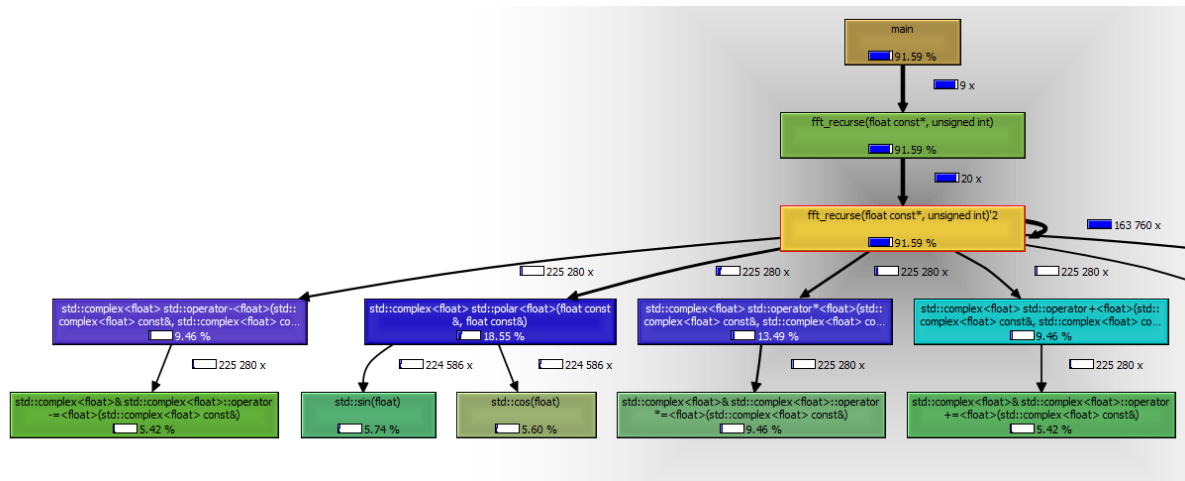
Takođe interesantno zapažanje je da RSWS varijanta ima najveći broj procenjenih instrukcija u odnosu na ostale varijante, ali je ipak bila brža u odnosu na neke druge varijante. Ovo može biti rezultat dubokog pipeline-ovanja koje je moguće sa AVX instrukcijama, koje su, između ostalog, korištene u RSWS varijanti.

### Analiza instrukcija

Ispod su priloženi grafovi poziva rutina za Cpp.Linux i ASM varijante.

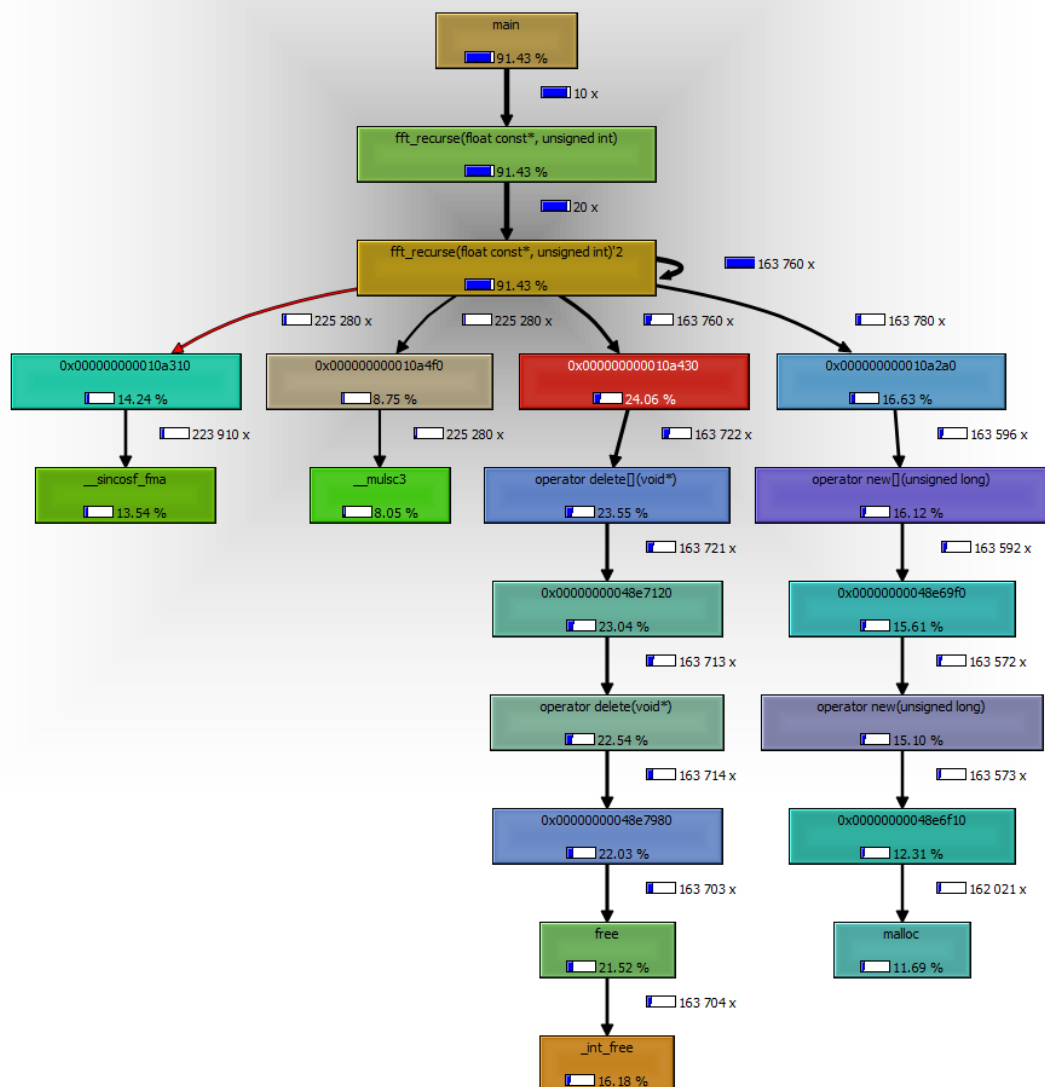
Vidimo da Cpp.Linux No opts varijanta značajan broj ciklusa provodi izvršavanjem funkcija za kreiranje kompleksnog broja iz polarne forme kompleksnog broja. Svekupno, 50.56%. Pri tome se koriste sinusna i kosinusna funkcija, koje zajedno uzimaju desetak posto ukupnog

izvršavanja FFT algoritma, što nije uopšte zanemarljivo obzirom da se obe funkcije moraju evaluirati minimalno za svaki ulazni uzorak u algoritmu.



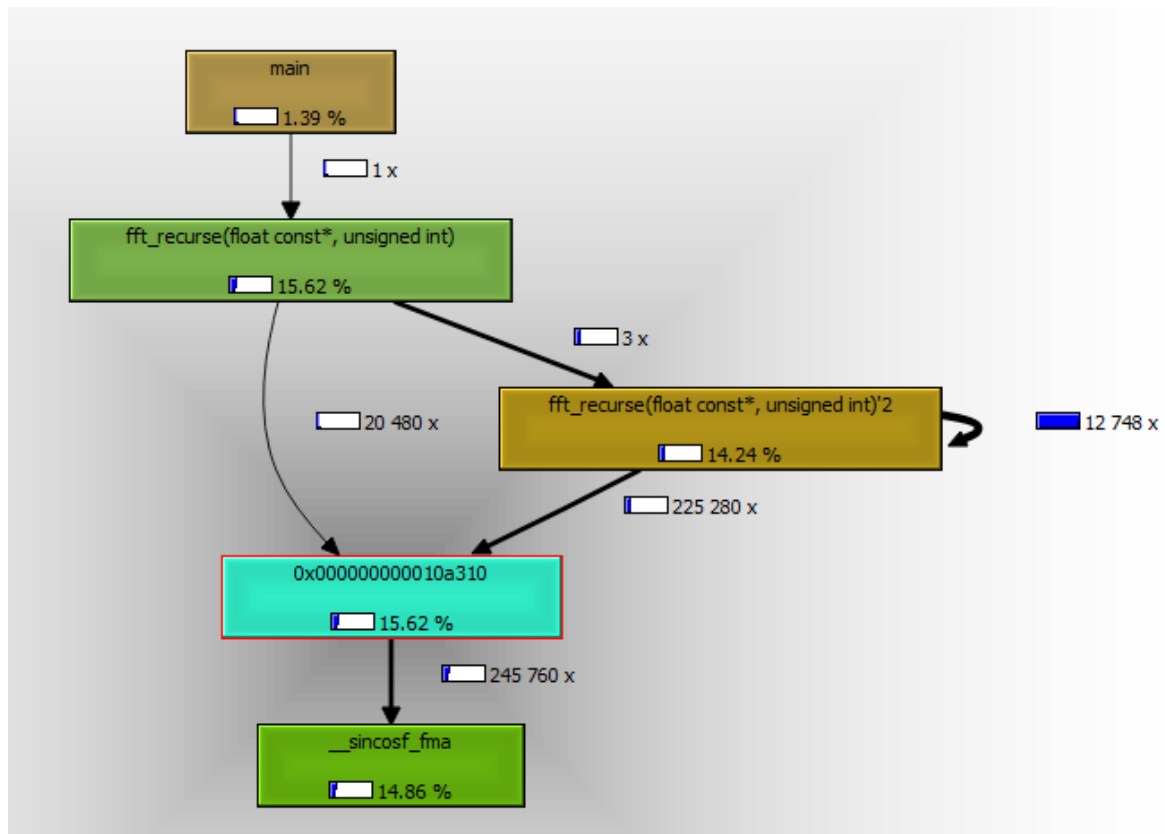
Prikaz 15 Cpp.Linux No opts

Primećujemo da -Os nivo optimizacija sažima konverzije iz polarnog oblika kompleksnih brojeva, potencijalno inline-ovanjem, kako bi se redukovao ukupan broj instrukcija i njihova dužina. Primećujemo takođe da se sada ne pozivaju funkcije STL-a za konverziju.



Prikaz 16 Cpp.Linux -Os

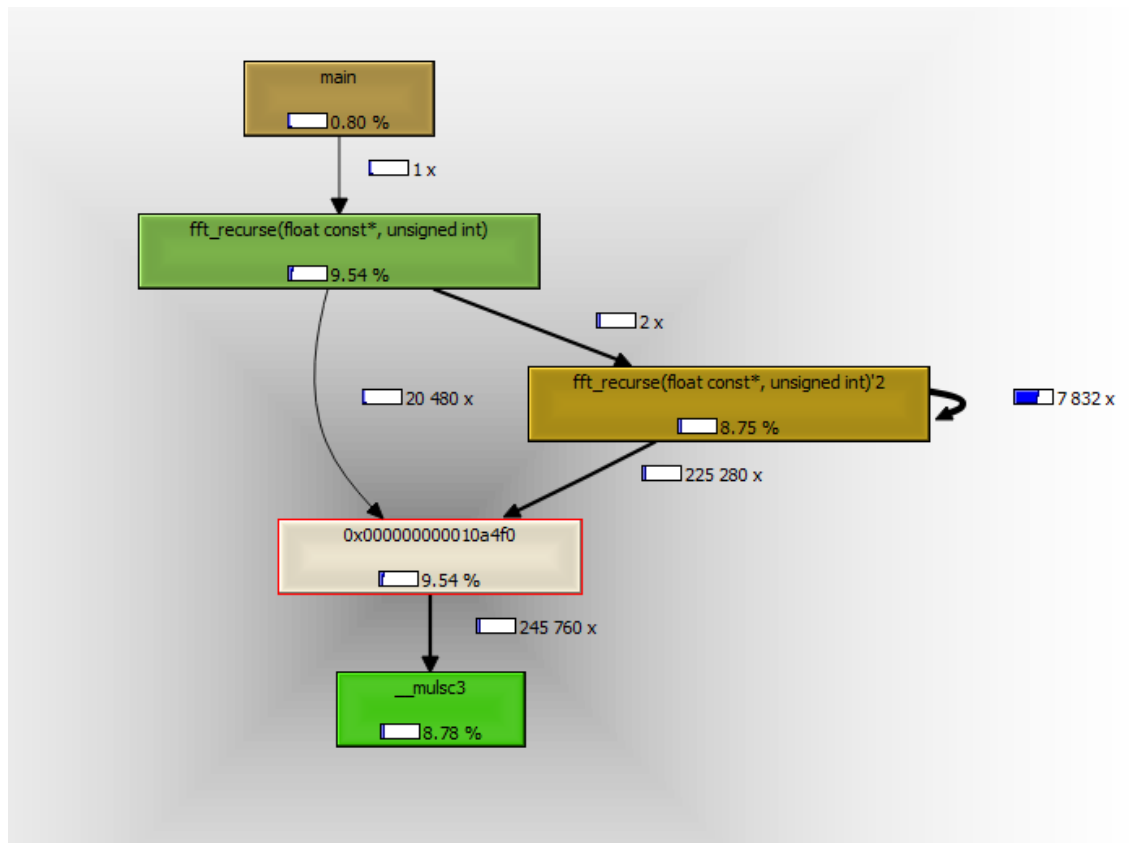
Umesto toga, koristi se rutina `_sincosf_fma`<sup>iii</sup> koja istovremeno evaluira sinusnu i kosinusnu funkciju, s tim da više ciklusa ide ka tome.



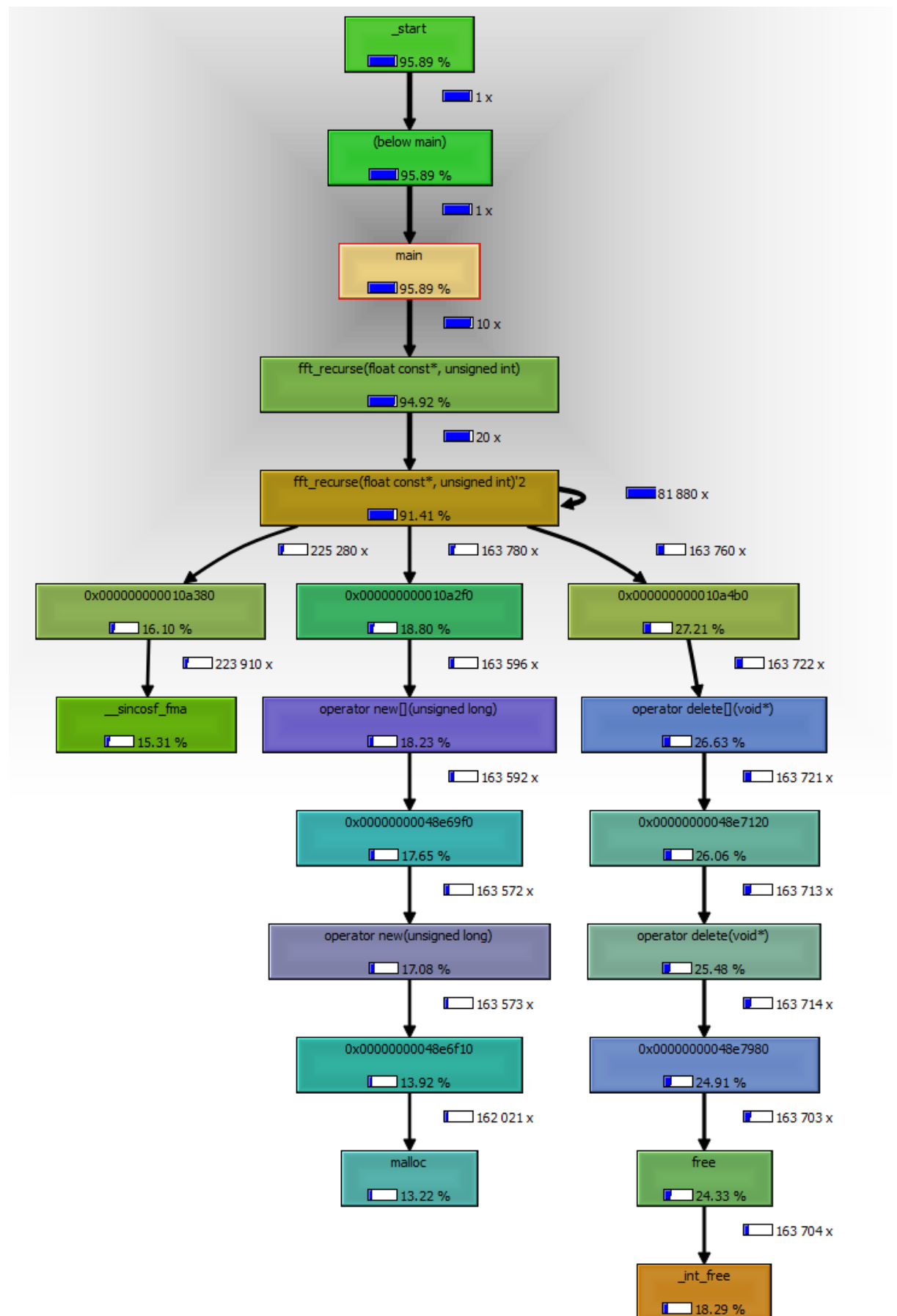
*Prikaz 17Cpp.Linux -Os \_\_sincosf\_fma*

Takođe koristi `_mulsc3iv` rutinu, koja se koristi za evaluiranje kompleksnih brojeva, pri čemu se broj  $a$  diže na stepen  $b$ .

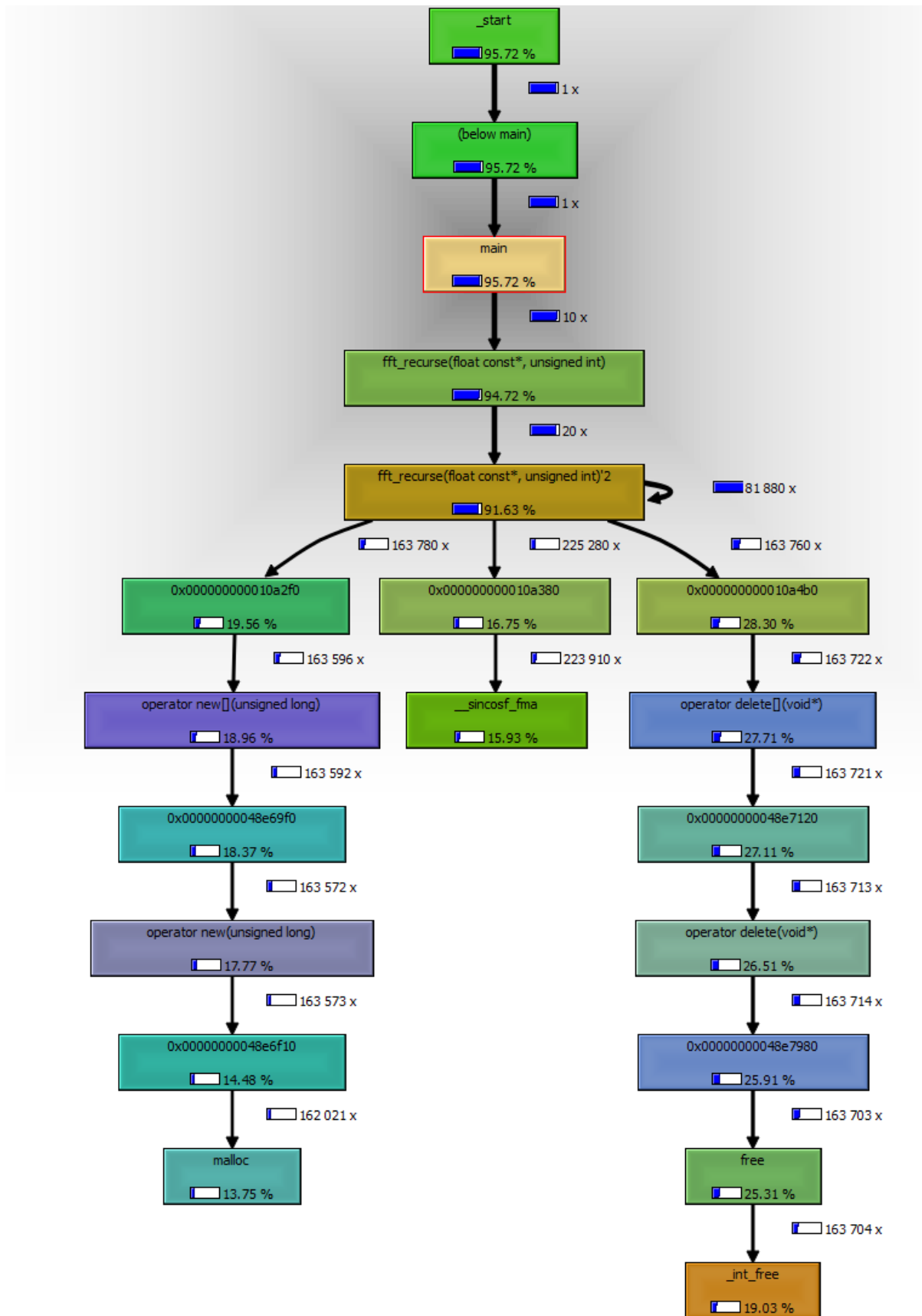


*Prikaz 18 Cpp.Linux -Os \_\_mulsc3*

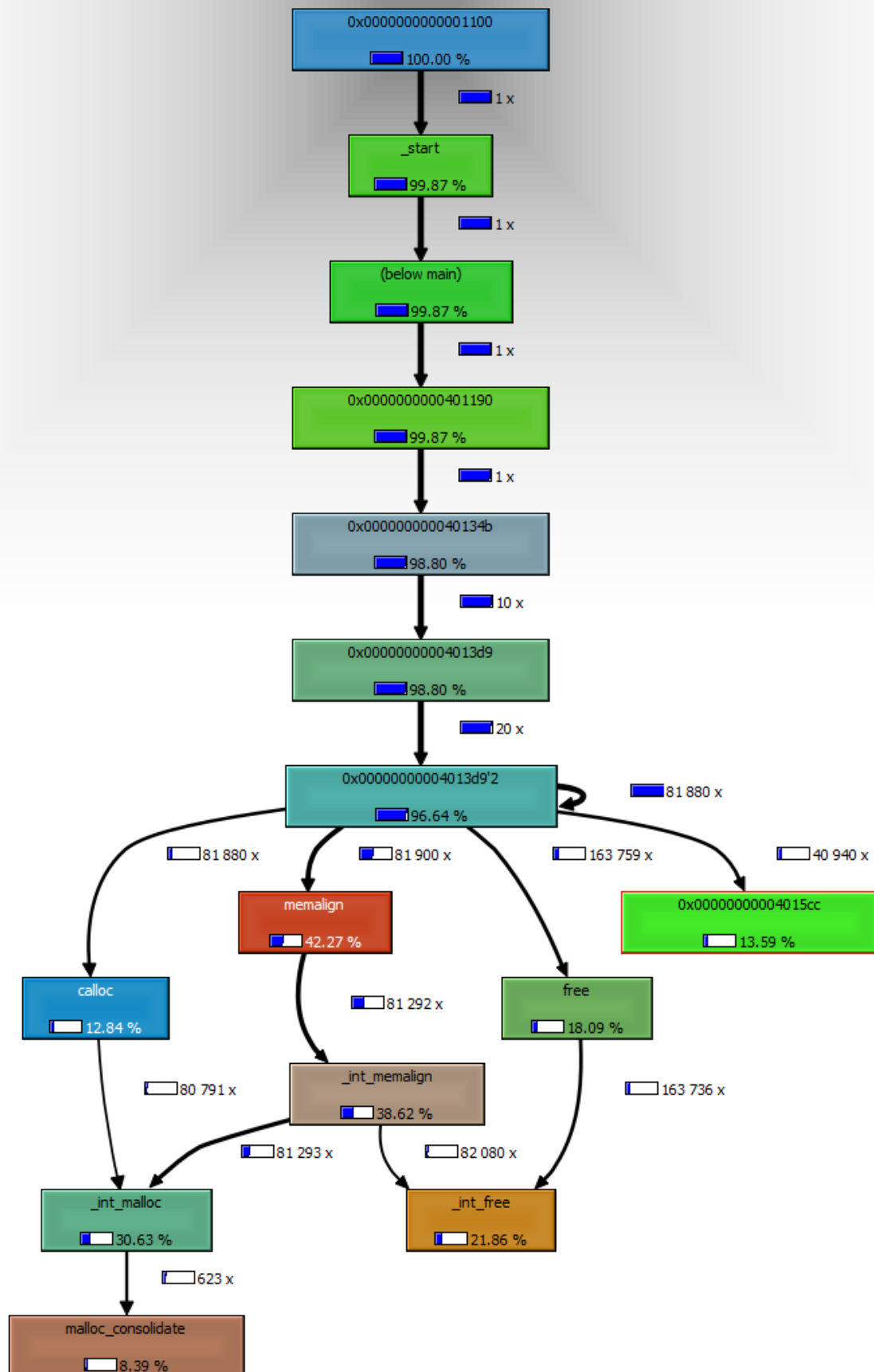
Interesantno je primetiti da -O2 nivo optimizacija koristi `_sincosf_fma` rutinu. Pritom, vidimo značajnu razliku u broju instrukcija za alokaciji i dealokaciji dinamičke memorije.



Sa nivoom -O3, imamo ponovo upotrebu `_sincosf_fma`, pri čemu su najverovatnije inline-ovane funkcije iz STL-a. Velika razlika je ponovo u načinu pozivanja i broju izvršenih instrukcija za alokaciju i dealokaciju dinamičke memorije.

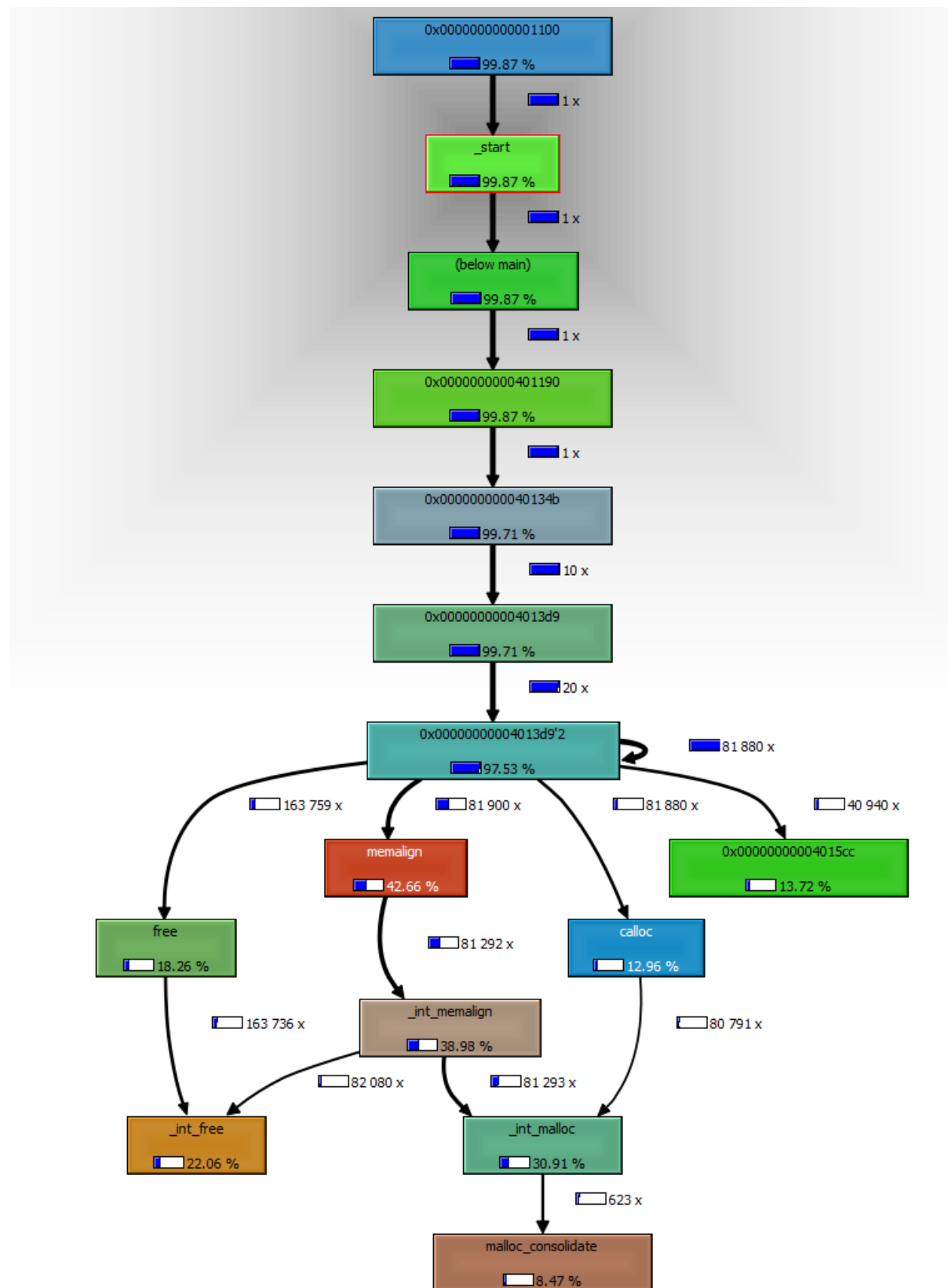


Interesantno je primetiti da samo 13.59% instrukcija odlazi ka samom algoritmu, dok preko 80% ciklusa u ASM No opts varijanti odlazi ka dinamičkom alociranju memorije pomoću `calloc`, `memalign` i `free` rutina. Ovo nam indikuje da, pri optimalnijem alociranu memorije, možemo videti značajna poboljšanja u radu ASM implementacija. Takođe bi bilo interesantno odrediti granicu kada se duže izvršavanje `memalign` rutine u kombinaciji sa `aligned AVX` instrukcijama ne isplati, u odnosu na situaciju gde se koristi `calloc/malloc` bez `align`-ovanja adresa, sa `unaligned AVX` instrukcijama.



Prikaz 21 ASM No opts

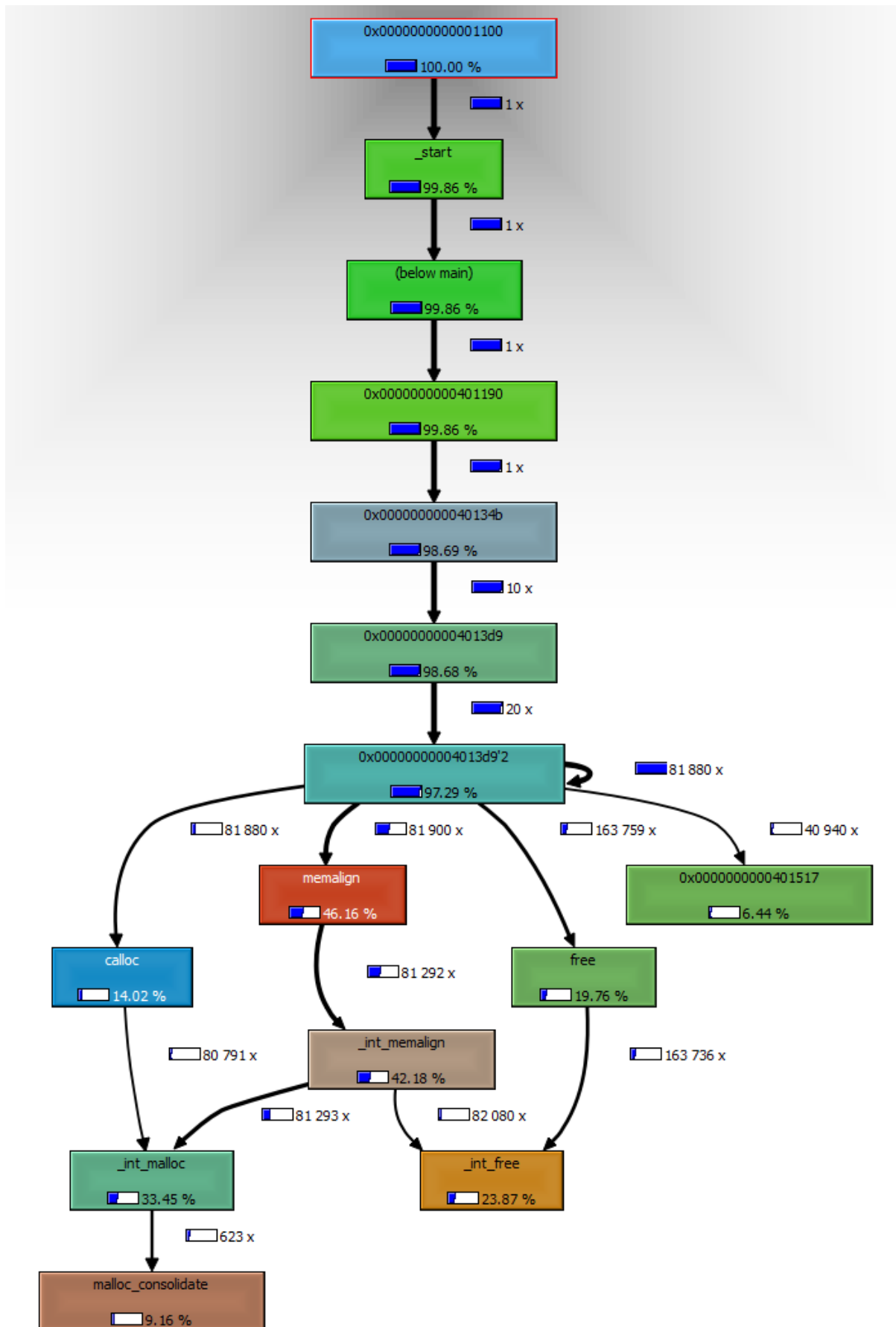
U strukturi poziva RSWs varijante, nema značajne razlike u odnosu na No opts varijantu.



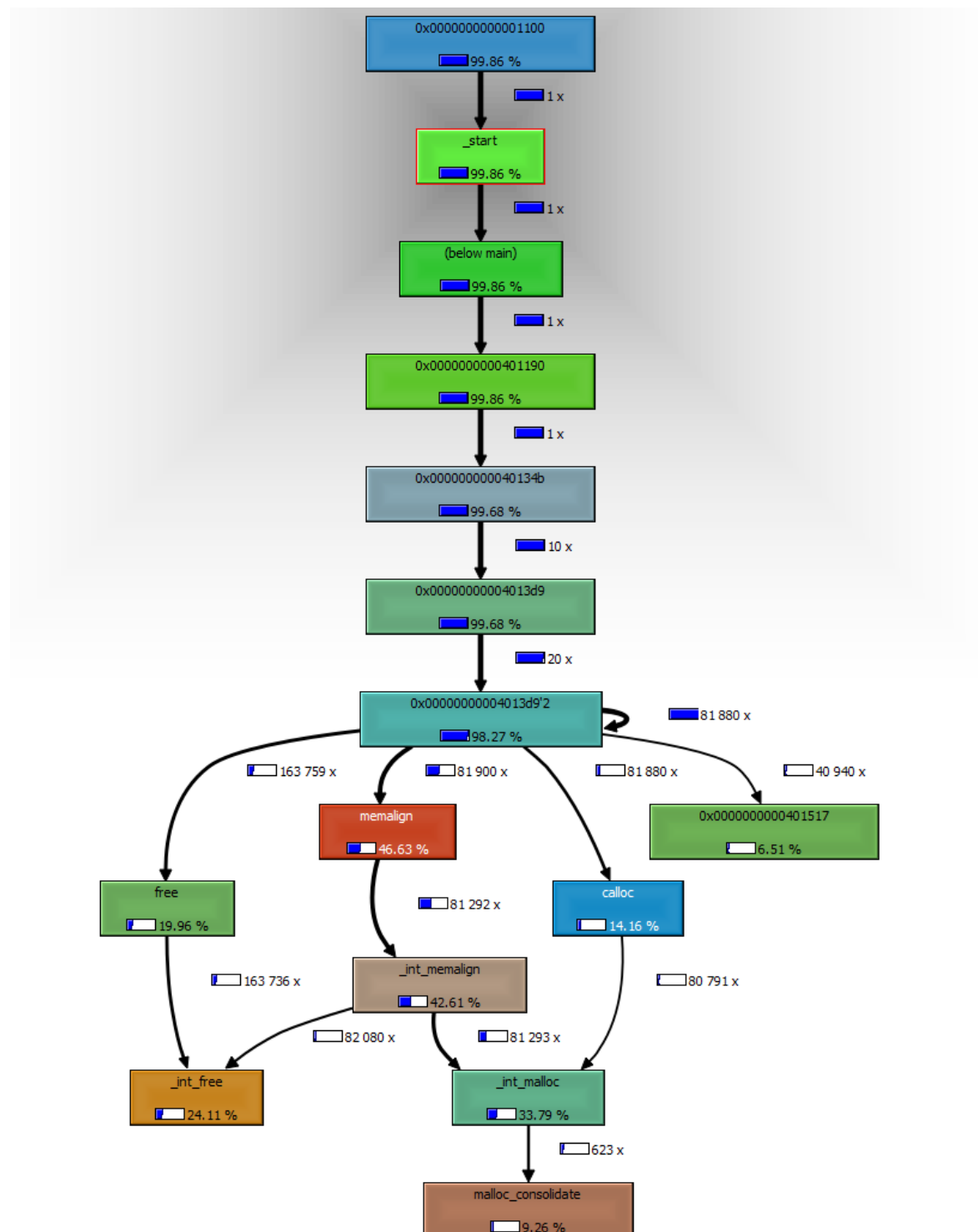
Prikaz 22 ASM RSWs

Primećujemo da u SIMD varijanti, još manji procenat ciklusa odlazi ka FFT rutini za izračunavanje, zbog upotrebe AVX instrukcija.





Kao i sa osnovnom RSWs varijantom, ne primećujemo značajnu razliku u odnosu na prethodnu varijantu.

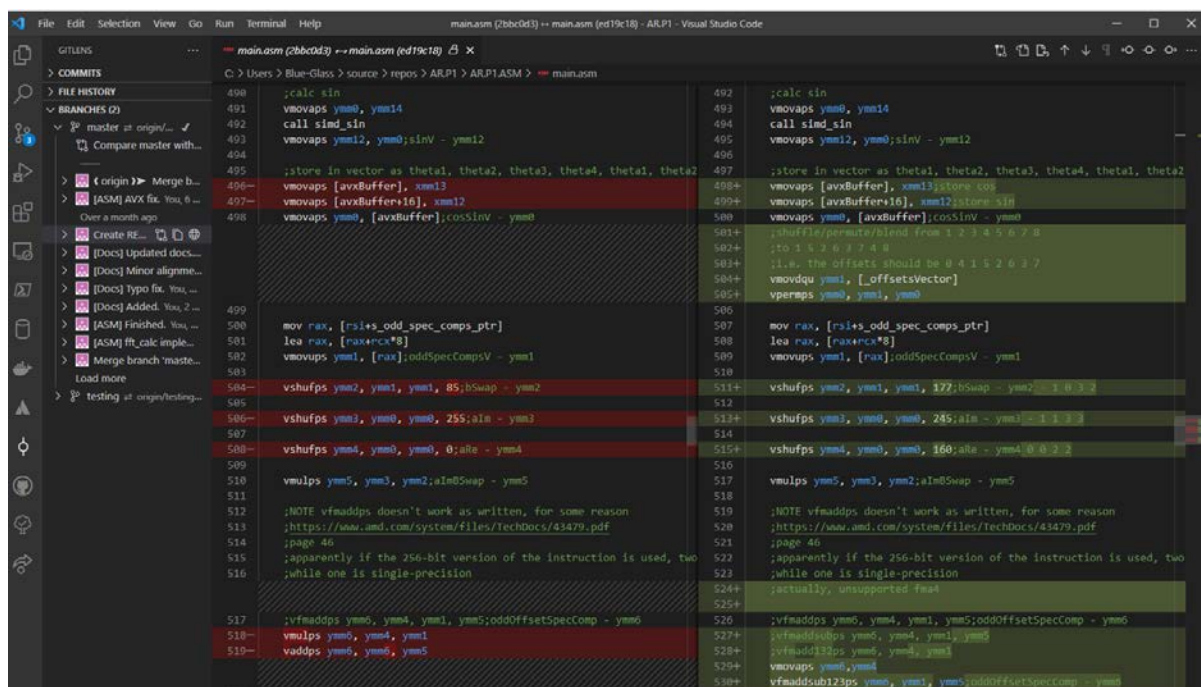


Prikaz 24 ASM SIMD, RSWs

## Napomena

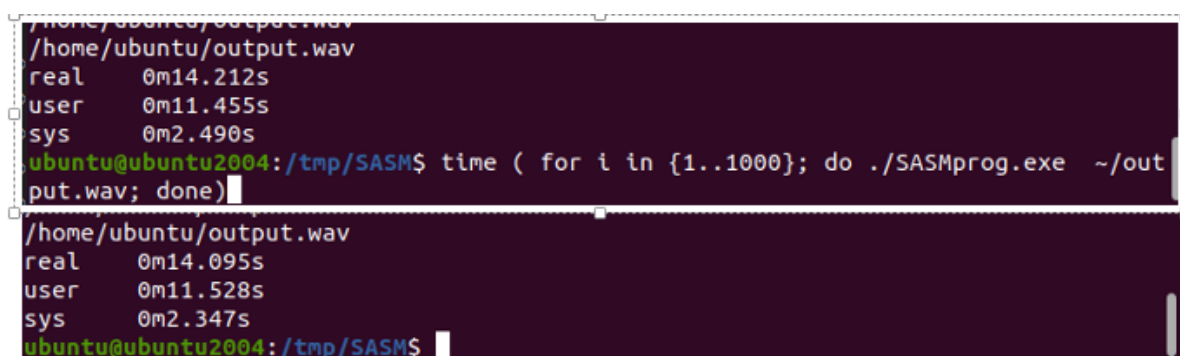
Nakon što su svi grafički i računski prikazi dobijeni, blago je modifikovana `fft_calc` rutina. Modifikovane su samo AVX instrukcije na sledeće načine:

1. korigovane VSHUFPS bit maske
2. dodata jedna VPERMPS instrukcija
3. zamenjene instrukcije množenja, sabiranja i oduzimanja jednom FMA instrukcijom



Prikaz 25 Modifikacije `fft_calc`

S tim u obziru, moguće je da dobijeni rezultati pri merenju budu drugačiji od tih iz ostatka ovog dokumenta. Inicijalna merenja daju sledeće rezultate za SIMD, RSWS varijantu.



Prikaz 26 Merenja SIMD,RSWS pri modifikaciji `fft_calc`

## Dodatak

C:\Users\Blue-Glass\Desktop\callgrind\_unoptimized.out.12762 [./AR.P1.Cpp.Linux.out ./output.wav]

File View Go Settings Help

Flat Profile

Search: (No Grouping)

Incl.	Self	Called	Function	Location
100.00	0.00	(0)	0x0000000000001100	ld-2.31.so
98.62	0.00	1	_start	AR.P1.Cpp.Linux.out
98.62	0.00	1	(below main)	libc-2.31.so: libc-start.c
98.55	0.11	1	main	AR.P1.Cpp.Linux.out: main.cpp, avx2intrin.h, ...
98.13	1.48	10	fft_recurse(float const*, unsigne...	AR.P1.Cpp.Linux.out: main.cpp
91.59	19.89	81 900	fft_recurse(float const*, unsigne...	AR.P1.Cpp.Linux.out: main.cpp
20.30	5.76	245 760	std::complex<float> std::polar<...	AR.P1.Cpp.Linux.out: complex
14.72	4.40	245 760	std::complex<float> std::operat...	AR.P1.Cpp.Linux.out: complex
10.32	4.40	245 760	std::complex<float> std::operat...	AR.P1.Cpp.Linux.out: complex
10.32	4.40	245 760	std::complex<float> std::operat...	AR.P1.Cpp.Linux.out: complex
10.32	4.70	245 760	std::complex<float> & std::com...	AR.P1.Cpp.Linux.out: complex
9.57	0.20	163 811	0x000000000010a630	(unknown)
9.37	0.20	163 813	operator delete[](void*)	libstdc++.so.6.0.28
9.17	0.20	163 818	0x000000000048e7120	(unknown)
8.96	0.20	163 817	operator delete(void*)	libstdc++.so.6.0.28
8.76	0.20	163 819	0x000000000048e7980	(unknown)
8.56	2.12	163 821	free	libc-2.31.so: malloc.c
6.73	6.73	778 240	std::complex<float>::complex(f...	AR.P1.Cpp.Linux.out: complex
6.62	0.20	163 811	0x000000000010a3d0	(unknown)
6.44	6.42	163 822	_int_free	libc-2.31.so: malloc.c
6.42	0.20	163 813	operator new[](unsigned long)	libstdc++.so.6.0.28
6.28	1.37	245 760	std::sin(float)	AR.P1.Cpp.Linux.out: cmath
6.22	0.20	163 818	0x000000000048e69f0	(unknown)
6.13	1.37	245 760	std::cos(float)	AR.P1.Cpp.Linux.out: cmath
6.01	1.11	163 817	operator new(unsigned long)	libstdc++.so.6.0.28
5.92	4.10	245 760	std::complex<float> & std::com...	AR.P1.Cpp.Linux.out: complex
5.92	4.10	245 760	std::complex<float> & std::com...	AR.P1.Cpp.Linux.out: complex
5.46	5.46	737 280	std::complex<float>::__rep() co...	AR.P1.Cpp.Linux.out: complex
4.95	0.20	163 819	0x000000000048e6f10	(unknown)
4.91	0.30	245 760	0x000000000010a4f0	(unknown)
4.76	0.30	245 760	0x000000000010a4d0	(unknown)
4.70	4.03	163 822	malloc	libc-2.31.so: malloc.c
4.61	4.61	245 760	__sinf_fma	libm-2.31.so: s_sinf.c, math_config.h, s_sinc...
4.46	4.46	245 760	__cosf_fma	libm-2.31.so: s_cosf.c, math_config.h, s_sinc...
3.79	0.30	245 760	0x000000000010a740	(unknown)
3.49	3.49	245 760	__mulsc3	libgcc_s.so.1
1.33	0.00	1	_dl_start	ld-2.31.so: rtld.c, dl-machine.h, get-dynamic-...
1.33	0.00	1	_dl_sysdep_start	ld-2.31.so: dl-sysdep.c, dl-sysdep.c, cpu-feat...
1.31	0.00	1	dl_main	ld-2.31.so: rtld.c, dl-prop.h, get-dynamic-info...
1.28	0.23	7	_dl_relocate_object	ld-2.31.so: dl-reloc.c, dl-machine.h, do-rel.h, ...
1.11	0.61	2 285	_dl_lookup_symbol_x	ld-2.31.so: dl-lookup.c
0.67	0.65	10 896	_int_malloc	libc-2.31.so: malloc.c
0.50	0.37	2 285	do_lookup_x	ld-2.31.so: dl-lookup.c, ldsodefs.h
0.33	40 960	1	std::complex<float>::operator=...	AR.P1.Cpp.Linux.out: complex
0.26	0.00	2 757	0x000000000010a620	(unknown)
0.26	0.06	2 757	std::istream::read(char*, long)	libstdc++.so.6.0.28
0.16	0.00	94	_dl_runtime_resolve_xsave2	ld-2.31.so: dl-trampoline.h
0.15	0.00	36	_dl_runtime_resolve_xsave	ld-2.31.so: dl-trampoline.h
0.15	0.06	2 757	std::basic_filebuf<char, std::cha...	libstdc++.so.6.0.28
0.12	0.08	2 270	check_match	ld-2.31.so: dl-lookup.c
0.09	0.00	2 757	0x000000000048e7f00	(unknown)
0.08	0.06	2 756	std::basic_streambuf<char, std::i...	libstdc++.so.6.0.28
0.07	0.01	130	_dl_fixup	ld-2.31.so: dl-runtime.c, dl-machine.h, dl-irel.h
0.07	0.00	1	__libc_csu_init	AR.P1.Cpp.Linux.out
0.06	0.00	1	_GLOBAL__sub_i_failedOpenStr	AR.P1.Cpp.Linux.out: main.cpp
0.06	0.00	1	__static_initialization_and_destr...	AR.P1.Cpp.Linux.out: main.cpp, iostream
0.06	0.00	1	0x000000000010a6a0	(unknown)
0.06	0.00	1	std::ios_base::Init::Init()	libstdc++.so.6.0.28
0.06	0.06	2 748	strcmp	ld-2.31.so: strcmp.S
0.05	0.00	2 757	0x000000000048e96a0	(unknown)
0.05	0.00	1	_dl_init	ld-2.31.so: dl-init.c
0.05	0.00	7	call_init.part.0	ld-2.31.so: dl-init.c
0.05	0.05	2 756	std::istream::sentry::sentry(std::i...	libstdc++.so.6.0.28
0.05	0.00	1	0x000000000010a6a0	libstdc++.so.6.0.28
0.05	0.00	34	0x000000000048e75c0	(unknown)
0.05	0.00	1	malloc_hook_ini	libc-2.31.so: hooks.c, arena.c, malloc.c
0.05	0.00	1	ptmalloc_init.part.0	libc-2.31.so: arena.c, malloc.c
0.05	0.00	34	0x000000000010be5d0	libstdc++.so.6.0.28
0.05	0.00	1	0x000000000048e7100	(unknown)
0.04	0.00	(0)	std::locale::_Impl::_Impl(unsign...	libstdc++.so.6.0.28
0.04	0.04	1	_dl_addr	libc-2.31.so: dl-addr.c
0.03	0.00	2 830	0x000000000048e9e00	(unknown)

Prikaz 27 Cpp.Linux No opts

C:\Users\Blue-Glass\Desktop\callgrind\_os.out.13050 [./AR.P1.Cpp.Linux.out /output.wav]

File View Go Settings Help

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Search: (No Grouping)

Incl.	Self	Called	Function	Location
100.00	0.00	(0)	0x0000000000001100	ld-2.31.so
96.56	0.00	1	_start	AR.P1.Cpp.Linux.out
96.56	0.00	1	(below main)	libc-2.31.so: libc-start.c
96.38	0.07	1	main	AR.P1.Cpp.Linux.out: main.cpp, basic_string...
95.53	1.88	10	fft_recurse(float const*, unsigne...	AR.P1.Cpp.Linux.out: main.cpp, complex
91.43	27.76	81 900	fft_recurse(float const*, unsigne...	AR.P1.Cpp.Linux.out: main.cpp, complex
24.07	0.51	163 811	0x0000000000010a430	(unknown)
23.57	0.51	163 813	operator delete[](void*)	libstdc++.so.6.0.28
23.06	0.51	163 818	0x0000000000048e7120	(unknown)
22.55	0.51	163 817	operator delete(void*)	libstdc++.so.6.0.28
22.04	0.51	163 819	0x0000000000048e7980	(unknown)
21.53	5.34	163 821	free	libc-2.31.so: malloc.c
16.65	0.51	163 811	0x0000000000010a2a0	(unknown)
16.19	16.16	163 822	_int_free	libc-2.31.so: malloc.c
16.14	0.51	163 813	operator new[](unsigned long)	libstdc++.so.6.0.28
15.64	0.51	163 818	0x0000000000048e69f0	(unknown)
15.62	0.76	245 760	0x0000000000010a310	(unknown)
15.13	2.80	163 817	operator new(unsigned long)	libstdc++.so.6.0.28
14.86	14.86	245 760	__sincosf_fma	libm-2.31.so: s_sincosf.c, math_config.h, s_si...
12.45	0.51	163 819	0x0000000000048e6f10	(unknown)
11.82	10.15	163 822	malloc	libc-2.31.so: malloc.c
9.54	0.76	245 760	0x0000000000010a4f0	(unknown)
8.78	8.78	245 760	__mulsc3	libgcc_s.so.1
3.32	0.00	1	_dl_start	ld-2.31.so: rtld.c, dl-machine.h, get-dynamic...
3.31	0.00	1	_dl_sysdep_start	ld-2.31.so: dl-sysdep.c, dl-sysdep.c, cpu-feat...
3.27	0.00	1	_dl_main	ld-2.31.so: rtld.c, dl-prop.h, get-dynamic-inf...
3.19	0.59	7	_dl_relocate_object	ld-2.31.so: dl-reloc.c, dl-machine.h, do-rel.h, ...
2.76	1.52	2 264	_dl_lookup_symbol_x	ld-2.31.so: dl-lookup.c
1.67	1.63	10 896	_int_malloc	libc-2.31.so: malloc.c
1.23	0.92	2 264	do_lookup_x	ld-2.31.so: dl-lookup.c, ldsodefs.h
0.67	0.01	2 757	0x0000000000010a420	(unknown)
0.66	0.16	2 757	std::istream::read(char*, long)	libstdc++.so.6.0.28
0.40	0.01	94	_dl_runtime_resolve_xsave2	ld-2.31.so: dl-trampoline.h
0.37	0.00	35	_dl_runtime_resolve_xsave	ld-2.31.so: dl-trampoline.h
0.37	0.14	2 757	std::basic_filebuf<char, std::cha...	libstdc++.so.6.0.28
0.31	0.19	2 249	check_match	ld-2.31.so: dl-lookup.c
0.23	0.01	2 757	0x0000000000048e7f00	(unknown)
0.21	0.15	2 756	std::basic_streambuf<char, std::...	libstdc++.so.6.0.28
0.17	0.02	129	_dl_fixup	ld-2.31.so: dl-runtime.c, dl-machine.h, dl-irel.h
0.16	0.00	1	_libc_csu_init	AR.P1.Cpp.Linux.out
0.16	0.00	1	_GLOBAL__sub_I_failedOpenStr	AR.P1.Cpp.Linux.out: main.cpp, iostream
0.16	0.00	1	0x0000000000010a480	(unknown)
0.16	0.00	1	std::ios_base::Init::Init()	libstdc++.so.6.0.28
0.14	0.14	2 707	strcmp	ld-2.31.so: strcmp.S
0.13	0.01	2 757	0x0000000000048e96a0	(unknown)
0.13	0.00	1	_dl_init	ld-2.31.so: dl-init.c
0.13	0.00	7	call_init.part.0	ld-2.31.so: dl-init.c
0.12	0.12	2 756	std::istream::sentry::sentry(std::i...	libstdc++.so.6.0.28
0.12	0.00	1	0x00000000000a6a60	libstdc++.so.6.0.28
0.12	0.00	34	0x0000000000048e75c0	(unknown)
0.12	0.00	1	malloc_hook_ini	libc-2.31.so: hooks.c, arena.c, malloc.c
0.12	0.00	1	ptmalloc_init.part.0	libc-2.31.so: arena.c, malloc.c
0.12	0.00	34	0x00000000000be5d0	libstdc++.so.6.0.28
0.11	0.00	1	0x0000000000048e7100	(unknown)
0.11	0.00	(0)	std::locale::_Impl::_Impl(unsign...	libstdc++.so.6.0.28
0.11	0.11	1	_dl_addr	libc-2.31.so: dl-addr.c
0.06	0.01	2 830	0x0000000000048e9e00	(unknown)
0.05	0.05	161	malloc Consolidate	libc-2.31.so: malloc.c
0.05	0.05	2 829	__memcpy_avx_unaligned_erms	libc-2.31.so: memmove-vec-unaligned-erms.S
0.05	0.00	1	_dl_map_object_deps	ld-2.31.so: dl-deps.c, scratch_buffer.h
0.05	0.00	13	0x000000000004001090	(unknown)
0.05	0.00	13	_dl_catch_exception	ld-2.31.so: dl-error-skeleton.c
0.04	0.00	13	_dl_map_object	ld-2.31.so: dl-load.c
0.04	0.00	1	0x0000000000048e68c0	(unknown)
0.04	0.00	(0)	std::ctype<wchar_t>::ctype(uns...	libstdc++.so.6.0.28
0.04	0.00	1	0x0000000000048e77d0	(unknown)
0.04	0.00	12	openaux	ld-2.31.so: dl-deps.c
0.04	0.00	(0)	std::ctype<wchar_t>::_M_initiali...	libstdc++.so.6.0.28
0.04	0.04	1	_GI__tunables_init	ld-2.31.so: dl-tunables.c, dl-tunables.h
0.03	0.00	10	0x0000000000048e9290	(unknown)
0.03	0.00	1	std::basic_ostream<char, std::c...	AR.P1.Cpp.Linux.out: quoted_string.h, basic...
0.03	0.00	10	0x0000000000048e9500	(unknown)

callgrind\_os.out.13050 [1] - Total Cycle Estimation Cost: 64 393 178

C:\Users\Blue-Glass\Desktop\callgrind\_o2.out.13326 [./AR.P1.Cpp.Linux.out ./output.wav]

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Cycle Estimation

Flat Profile

Search: (No Grouping)

Incl.	Self	Called	Function	Location
100.00	0.00	(0)	0x0000000000001100	ld-2.31.so
96.08	0.00	1	_start	AR.P1.Cpp.Linux.out
96.08	0.00	1	(below main)	libc-2.31.so: libc-start.c
95.89	0.08	1	main	AR.P1.Cpp.Linux.out: main.cpp, ost...
94.92	1.91	10	fft_recurse(float const*, unsigne...	AR.P1.Cpp.Linux.out: main.cpp, co...
91.41	29.31	81 900	fft_recurse(float const*, unsigne...	AR.P1.Cpp.Linux.out: main.cpp, co...
27.22	0.58	163 811	0x000000000010a4b0	(unknown)
26.65	0.58	163 813	operator delete[](void*)	libstdc++.so.6.0.28
26.07	0.58	163 814	0x000000000048e7120	(unknown)
25.50	0.58	163 817	operator delete(void*)	libstdc++.so.6.0.28
24.92	0.58	163 819	0x000000000048e7980	(unknown)
24.35	6.04	163 821	free	libc-2.31.so: malloc.c
18.83	0.58	163 811	0x000000000010a2f0	(unknown)
18.31	18.27	163 822	_int_free	libc-2.31.so: malloc.c
18.25	0.58	163 813	operator new[](unsigned long)	libstdc++.so.6.0.28
17.68	0.58	163 818	0x000000000048e69f0	(unknown)
17.67	0.86	245 760	0x000000000010a380	(unknown)
17.10	3.16	163 817	operator new(unsigned long)	libstdc++.so.6.0.28
16.80	16.80	245 760	__sincosf_fma	libm-2.31.so: s_sincosf.c, math_con...
14.07	0.58	163 819	0x000000000048e6f10	(unknown)
13.36	11.47	163 822	malloc	libc-2.31.so: malloc.c
3.77	0.00	1	_dl_start	ld-2.31.so: rtld.c, dl-machine.h, get...
3.77	0.00	1	_dl_sysdep_start	ld-2.31.so: dl-sysdep.c, dl-sysdep.c,...
3.73	0.00	1	dl_main	ld-2.31.so: rtld.c, dl-prop.h, get-dyn...
3.63	0.67	7	_dl_relocate_object	ld-2.31.so: dl-reloc.c, dl-machine.h,...
3.14	1.73	2 273	_dl_lookup_symbol_x	ld-2.31.so: dl-lookup.c
1.89	1.84	10 896	_int_malloc	libc-2.31.so: malloc.c
1.41	1.05	2 273	do_lookup_x	ld-2.31.so: dl-lookup.c, ldsdefs.h
0.75	0.01	2 757	0x000000000010a4a0	(unknown)
0.74	0.18	2 757	std::istream::read(char*, long)	libstdc++.so.6.0.28
0.45	0.01	92	_dl_runtime_resolve_xsave2	ld-2.31.so: dl-trampoline.h
0.42	0.00	36	_dl_runtime_resolve_xsave	ld-2.31.so: dl-trampoline.h
0.42	0.16	2 757	std::basic_filebuf<char, std::cha...	libstdc++.so.6.0.28
0.35	0.22	2 258	check_match	ld-2.31.so: dl-lookup.c
0.26	0.01	2 757	0x000000000048e7f00	(unknown)
0.24	0.17	2 756	std::basic_streambuf<char, std::...	libstdc++.so.6.0.28
0.19	0.02	128	_dl_fixup	ld-2.31.so: dl-runtime.c, dl-machin...
0.19	0.00	1	_libc_csu_init	AR.P1.Cpp.Linux.out
0.18	0.00	1	_GLOBAL__sub_I_failedOpenStr	AR.P1.Cpp.Linux.out: main.cpp, ios...
0.18	0.00	1	0x000000000010a510	(unknown)
0.18	0.00	1	std::ios_base::Init::Init()	libstdc++.so.6.0.28
0.16	0.16	2 734	strcmp	ld-2.31.so: strcmp.S
0.15	0.01	2 757	0x000000000048e96a0	(unknown)
0.15	0.00	1	_dl_init	ld-2.31.so: dl-init.c
0.15	0.00	7	call_init.part.0	ld-2.31.so: dl-init.c
0.14	0.14	2 756	std::istream::sentry::sentry(std::i...	libstdc++.so.6.0.28
0.13	0.00	1	0x000000000000a6a0	libstdc++.so.6.0.28
0.13	0.00	33	0x000000000048e75c0	(unknown)
0.13	0.00	1	malloc_hook_ini	libc-2.31.so: hooks.c, arena.c, mallo...
0.13	0.00	1	ptmalloc_init.part.0	libc-2.31.so: arena.c, malloc.c
0.13	0.00	34	0x000000000000be5d0	libstdc++.so.6.0.28
0.13	0.00	1	0x000000000048e7100	(unknown)
0.13	0.00	(0)	std::locale::_Impl::_Impl(unsign...	libstdc++.so.6.0.28
0.13	0.13	1	_dl_addr	libc-2.31.so: dl-addr.c
0.07	0.01	2 828	0x000000000048e9e00	(unknown)
0.06	0.06	161	malloc Consolidate	libc-2.31.so: malloc.c
0.06	0.06	2 829	__memcpy_avx_unaligned_erms	libc-2.31.so: memmove-vec-unalig...
0.05	0.00	1	_dl_map_object_deps	ld-2.31.so: dl-deps.c, scratch_buffer.h
0.05	0.00	13	0x00000000004001090	(unknown)
0.05	0.00	13	_dl_catch_exception	ld-2.31.so: dl-error-skeleton.c
0.05	0.00	13	_dl_map_object	ld-2.31.so: dl-load.c
0.05	0.00	1	0x000000000048e68c0	(unknown)
0.05	0.00	(0)	std::ctype<wchar_t>::ctype(uns...	libstdc++.so.6.0.28
0.05	0.00	1	0x000000000048e77d0	(unknown)
0.05	0.00	12	openaux	ld-2.31.so: dl-deps.c
0.04	0.00	(0)	std::ctype<wchar_t>::_M_initiali...	libstdc++.so.6.0.28
0.04	0.04	1	_GI__tunables_init	ld-2.31.so: dl-tunables.c, dl-tunable...
0.04	0.00	8	0x000000000048e9290	(unknown)
0.04	0.00	1	std::basic_ostream<char, std::c...	AR.P1.Cpp.Linux.out: quoted_string...
0.03	0.00	10	0x000000000048e9500	(unknown)
0.03	0.00	1	_dl_receive_error	ld-2.31.so: dl-error-skeleton.c
0.03	0.00	1	version_check_doit	ld-2.31.so: rtld.c

callgrind\_o2.out.13326 [1] - Total Cycle Estimation Cost: 56 950 372



C:\Users\Blue-Glass\Desktop\callgrind\_o3.out.13602 [./AR.P1.Cpp.Linux.out ./output.wav]

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Cycle Estimation

Flat Profile

Search: (No Grouping)

Incl.	Self	Called	Function	Location
100.00	0.00	(0)	0x0000000000001100	ld-2.31.so
95.93	0.00	1	_start	AR.P1.Cpp.Linux.out
95.93	0.00	1	(below main)	libc-2.31.so: libc-start.c
95.72	0.09	1	main	AR.P1.Cpp.Linux.out: main.cpp, ostream, bas...
94.72	1.41	10	fft_recurse(float const*, unsigne...	AR.P1.Cpp.Linux.out: main.cpp, complex
91.63	27.02	81 900	fft_recurse(float const*, unsigne...	AR.P1.Cpp.Linux.out: main.cpp, complex
28.32	0.60	163 811	0x0000000000010a4b0	(unknown)
27.72	0.60	163 813	operator delete[](void*)	libstdc++.so.6.0.28
27.12	0.60	163 814	0x000000000004e7120	(unknown)
26.53	0.60	163 817	operator delete(void*)	libstdc++.so.6.0.28
25.93	0.60	163 819	0x000000000004e7980	(unknown)
25.33	6.28	163 821	free	libc-2.31.so: malloc.c
19.59	0.60	163 811	0x0000000000010a2f0	(unknown)
19.04	19.01	163 822	_int_free	libc-2.31.so: malloc.c
18.99	0.60	163 813	operator new[](unsigned long)	libstdc++.so.6.0.28
18.39	0.60	163 818	0x000000000004e69f0	(unknown)
18.38	0.90	245 760	0x0000000000010a380	(unknown)
17.79	3.29	163 817	operator new(unsigned long)	libstdc++.so.6.0.28
17.48	17.48	245 760	_sincosf_fma	libm-2.31.so: s_sincosf.c, math_config.h, s_si...
14.64	0.60	163 819	0x000000000004e6f10	(unknown)
13.90	11.94	163 822	malloc	libc-2.31.so: malloc.c
3.92	0.00	1	_dl_start	ld-2.31.so: rtld.c, dl-machine.h, get-dynamic...
3.92	0.00	1	_dl_sysdep_start	ld-2.31.so: dl-sysdep.c, dl-sysdep.c, cpu-feat...
3.87	0.00	1	dl_main	ld-2.31.so: rtld.c, dl-prop.h, get-dynamic-inf...
3.77	0.69	7	_dl_relocate_object	ld-2.31.so: dl-reloc.c, dl-machine.h, do-rel.h, ...
3.26	1.80	2 273	_dl_lookup_symbol_x	ld-2.31.so: dl-lookup.c
1.97	1.92	10 896	_int_malloc	libc-2.31.so: malloc.c
1.46	1.09	2 273	do_lookup_x	ld-2.31.so: dl-lookup.c, ldsdefs.h
0.78	0.01	2 757	0x0000000000010a4a0	(unknown)
0.77	0.19	2 757	std::istream::read(char*, long)	libstdc++.so.6.0.28
0.47	0.01	92	_dl_runtime_resolve_xsave2	ld-2.31.so: dl-trampoline.h
0.44	0.00	36	_dl_runtime_resolve_xsave	ld-2.31.so: dl-trampoline.h
0.43	0.17	2 757	std::basic_filebuf<char, std::cha...	libstdc++.so.6.0.28
0.36	0.22	2 258	check_match	ld-2.31.so: dl-lookup.c
0.27	0.01	2 757	0x000000000004e7f00	(unknown)
0.25	0.18	2 756	std::basic_streambuf<char, std::i...	libstdc++.so.6.0.28
0.20	0.02	128	_dl_fixup	ld-2.31.so: dl-runtime.c, dl-machine.h, dl-irel.h
0.19	0.00	1	_libc_csu_init	AR.P1.Cpp.Linux.out
0.19	0.00	1	_GLOBAL__sub_I_failedOpenStr	AR.P1.Cpp.Linux.out: main.cpp, iostream
0.19	0.00	1	0x0000000000010a510	(unknown)
0.19	0.00	1	std::ios_base::Init::Init()	libstdc++.so.6.0.28
0.17	0.17	2 734	stricmp	ld-2.31.so: stricmp.S
0.15	0.01	2 757	0x000000000004e96a0	(unknown)
0.15	0.00	1	_dl_init	ld-2.31.so: dl-init.c
0.15	0.00	7	call_init.part.0	ld-2.31.so: dl-init.c
0.14	0.14	2 756	std::istream::sentry::sentry(std::i...	libstdc++.so.6.0.28
0.14	0.00	1	0x000000000000a6a60	libstdc++.so.6.0.28
0.14	0.00	33	0x000000000004e75c0	(unknown)
0.14	0.00	1	malloc_hook_ini	libc-2.31.so: hooks.c, arena.c, malloc.c
0.14	0.00	1	ptmalloc_init.part.0	libc-2.31.so: arena.c, malloc.c
0.14	0.00	34	0x000000000000be5d0	libstdc++.so.6.0.28
0.13	0.00	1	0x000000000004e7100	(unknown)
0.13	0.00	(0)	std::locale::_Impl::_Impl(unsign...	libstdc++.so.6.0.28
0.13	0.13	1	_dl_addr	libc-2.31.so: dl-addr.c
0.07	0.01	2 828	0x000000000004e9e00	(unknown)
0.06	0.06	161	malloc Consolidate	libc-2.31.so: malloc.c
0.06	0.06	2 829	__memcpy_avx_unaligned_erms	libc-2.31.so: memmove-vec-unaligned-erms.S
0.06	0.00	1	_dl_map_object_deps	ld-2.31.so: dl-deps.c, scratch_buffer.h
0.05	0.00	13	0x000000000004001090	(unknown)
0.05	0.00	13	_dl_catch_exception	ld-2.31.so: dl-error-skeleton.c
0.05	0.00	13	_dl_map_object	ld-2.31.so: dl-load.c
0.05	0.00	1	0x000000000004e68c0	(unknown)
0.05	0.00	(0)	std::ctype<wchar_t>::ctype(uns...	libstdc++.so.6.0.28
0.05	0.00	1	0x000000000004e77d0	(unknown)
0.05	0.00	12	openaux	ld-2.31.so: dl-deps.c
0.05	0.00	(0)	std::ctype<wchar_t>::M_initiali...	libstdc++.so.6.0.28
0.04	0.04	1	_GI__tunables_init	ld-2.31.so: dl-tunables.c, dl-tunables.h
0.04	0.00	8	0x000000000004e9290	(unknown)
0.04	0.00	1	std::basic_ostream<char, std::c...	AR.P1.Cpp.Linux.out: quoted_string.h, basic_...
0.03	0.00	10	0x000000000004e9500	(unknown)
0.03	0.00	1	_dl_receive_error	ld-2.31.so: dl-error-skeleton.c
0.03	0.00	1	version_check_doit	ld-2.31.so: rtld.c

callgrind\_o3.out.13602 [1] - Total Cycle Estimation Cost: 54 740 209

C:\Users\Blue-Glass\Desktop\callgrind\_rsws\_unoptimized.out.31110 [/SASMprog\_rsws\_unoptimized.exe ./output.wa]

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Flat Profile

Search: (No Grouping)

Incl.	Self	Called	Function	Location
100.00	0.00	(0)	0x0000000000001100	ld-2.31.so
99.87	0.00	1	_start	SASMprog_rsws_unoptimized.exe
99.87	0.00	1	(below main)	libc-2.31.so: libc-start.c
99.87	0.00	1	0x0000000000040190	SASMprog_rsws_unoptimized.exe
98.80	0.00	1	0x0000000000040134b	SASMprog_rsws_unoptimized.exe
98.80	0.00	10	0x000000000004013d9	SASMprog_rsws_unoptimized.exe
96.64	5.02	81 900	0x000000000004013d9'2	SASMprog_rsws_unoptimized.exe
42.59	3.67	81 910	memalign	libc-2.31.so: malloc.c
38.92	6.34	81 911	_int_memalign	libc-2.31.so: malloc.c
30.90	20.30	163 813	_int_malloc	libc-2.31.so: malloc.c
21.92	21.90	246 514	_int_free	libc-2.31.so: malloc.c
18.10	3.67	163 810	free	libc-2.31.so: malloc.c
14.82	14.82	40 950	0x000000000004015cc	SASMprog_rsws_unoptimized.exe
13.01	6.59	81 899	calloc	libc-2.31.so: malloc.c
10.41	7.40	628	malloc Consolidate	libc-2.31.so: malloc.c
3.22	3.22	161 404	unlink_chunk.isra.0	libc-2.31.so: malloc.c
2.75	2.75	40 950	0x000000000004016ed	SASMprog_rsws_unoptimized.exe
2.49	2.49	40 950	0x000000000004016d0	SASMprog_rsws_unoptimized.exe
0.99	0.85	1	0x000000000004017dc	SASMprog_rsws_unoptimized.exe
0.63	0.01	2 540	0x000000000004871560	(unknown)
0.62	0.62	2 540	__memset_avx2_unaligned_erms	libc-2.31.so: memset-vec-unaligned-erms.S
0.14	0.14	44 097	0x00000000000401a38	SASMprog_rsws_unoptimized.exe
0.13	0.00	1	_dl_start	ld-2.31.so: rtld.c, dl-machine.h, get-dynamic...
0.13	0.00	1	_dl_sysdep_start	ld-2.31.so: dl-sysdep.c, dl-sysdep.c, cpu-feat...
0.10	0.00	1	dl_main	ld-2.31.so: rtld.c, get-dynamic-info.h, setup-...
0.09	0.00	5	_dl_runtime_resolve_xsave	ld-2.31.so: dl-trampoline.h
0.08	0.00	1	0x00000000000401e8c	SASMprog_rsws_unoptimized.exe
0.08	0.00	2	0x00000000000401ea5	SASMprog_rsws_unoptimized.exe
0.08	0.00	2	_IO_file_xsputn@@GLIBC_2.2.5	libc-2.31.so: fileops.c, libioP.h
0.08	0.00	3	_IO_file_overflow@@GLIBC_2.2.5	libc-2.31.so: fileops.c
0.08	0.00	1	_IO_doallocbuf	libc-2.31.so: genops.c, libioP.h
0.08	0.00	1	_IO_file_doallocate	libc-2.31.so: filedoalloc.c, libioP.h, sysmacros.h
0.08	0.00	1	0x000000000004871310	(unknown)
0.08	0.00	1	malloc	libc-2.31.so: malloc.c
0.08	0.00	1	malloc_hook_ini	libc-2.31.so: hooks.c, arena.c, malloc.c
0.08	0.03	4	_dl_relocate_object	ld-2.31.so: dl-reloc.c, dl-machine.h, do-rel.h, ...
0.08	0.00	1	ptmalloc_init.part.0	libc-2.31.so: arena.c, malloc.c
0.08	0.08	1	_dl_addr	libc-2.31.so: dl-addr.c
0.05	0.02	95	_dl_lookup_symbol_x	ld-2.31.so: dl-lookup.c
0.03	0.02	95	do_lookup_x	ld-2.31.so: dl-lookup.c, ldsymbols.h
0.03	0.03	1	_GI__tunables_init	ld-2.31.so: dl-tunables.c, dl-tunables.h
0.01	0.00	3	0x000000000004001090	(unknown)
0.01	0.00	3	_dl_catch_exception	ld-2.31.so: dl-error-skeleton.c
0.01	0.00	3	_dl_map_object	ld-2.31.so: dl-load.c
0.01	0.01	87	check_match	ld-2.31.so: dl-lookup.c
0.01	0.00	1	_dl_map_object_deps	ld-2.31.so: dl-deps.c, scratch_buffer.h
0.01	0.00	2	openaux	ld-2.31.so: dl-deps.c
0.00	0.00	151	strcmp	ld-2.31.so: strcmp.S
0.00	0.00	7	_dl_fixup	ld-2.31.so: dl-runtime.c, dl-machine.h
0.00	0.00	2	_dl_map_object_from_fd	ld-2.31.so: dl-load.c, dl-fileid.h, dl-map-seg...
0.00	0.00	1	handle_preload_list	ld-2.31.so: rtld.c
0.00	0.00	1	0x0000000000040010f0	(unknown)
0.00	0.00	1	_dl_catch_error	ld-2.31.so: dl-error-skeleton.c
0.00	0.00	1	map_doit	ld-2.31.so: rtld.c
0.00	0.00	1	_dl_receive_error	ld-2.31.so: dl-error-skeleton.c
0.00	0.00	1	version_check_doit	ld-2.31.so: rtld.c
0.00	0.00	1	_dl_check_all_versions	ld-2.31.so: dl-version.c
0.00	0.00	4	_dl_check_map_versions	ld-2.31.so: dl-version.c
0.00	0.00	1	_dl_init	ld-2.31.so: dl-init.c
0.00	0.00	4	call_init.part.0	ld-2.31.so: dl-init.c
0.00	0.00	1	_dl_init_paths	ld-2.31.so: dl-load.c
0.00	0.00	1	init_cacheinfo	libc-2.31.so: cacheinfo.c
0.00	0.00	2	_dl_runtime_resolve_xsave2	ld-2.31.so: dl-trampoline.h
0.00	0.00	3	handle_intel.constprop.0	libc-2.31.so: cacheinfo.c
0.00	0.00	1	open_path	ld-2.31.so: dl-load.c
0.00	0.00	1	_dl_load_cache_lookup	ld-2.31.so: dl-cache.c, dl-procinfo.h, dl-cach...
0.00	0.00	14	_dl_name_match_p	ld-2.31.so: dl-misc.c
0.00	0.00	6	intel_check_word.isra.0	libc-2.31.so: cacheinfo.c, stdlib-bsearch.h
0.00	0.00	1	exit	libc-2.31.so: exit.c
0.00	0.00	1	__run_exit_handlers	libc-2.31.so: exit.c, lowlevellock.h
0.00	0.00	3	_dl_new_object	ld-2.31.so: dl-object.c
0.00	0.00	12	0x000000000004871450	(unknown)

callgrind\_rsws\_unoptimized.out.31110 [1] - Total Cycle Estimation Cost: 93 716 528



C:\Users\Blue-Glass\Desktop\callgrind\_rsws.out.31092 [./SASMprog\_rsws.exe ./output.wav]

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Cycle Estimation

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Search: (No Grouping)

Incl.	Self	Called	Function	Location
100.00	0.00	(0)	0x0000000000001100	ld-2.31.so
99.87	0.00	1	_start	SASMprog_rsws.exe
99.87	0.00	1	(below main)	libc-2.31.so: libc-start.c
99.87	0.00	1	0x00000000000401190	SASMprog_rsws.exe
99.71	0.00	1	0x0000000000040134b	SASMprog_rsws.exe
99.71	0.00	10	0x000000000004013d9	SASMprog_rsws.exe
97.53	5.07	81 900	0x000000000004013d9'2	SASMprog_rsws.exe
42.98	3.70	81 910	memalign	libc-2.31.so: malloc.c
39.28	6.39	81 911	_int_memalign	libc-2.31.so: malloc.c
31.18	20.48	163 813	_int_malloc	libc-2.31.so: malloc.c
22.12	22.10	246 514	_int_free	libc-2.31.so: malloc.c
18.27	3.70	163 810	free	libc-2.31.so: malloc.c
14.95	14.95	40 950	0x000000000004015cc	SASMprog_rsws.exe
13.13	6.65	81 899	calloc	libc-2.31.so: malloc.c
10.51	7.47	628	malloc Consolidate	libc-2.31.so: malloc.c
3.25	3.25	161 404	unlink_chunk.isra.0	libc-2.31.so: malloc.c
2.78	2.78	40 950	0x000000000004016ed	SASMprog_rsws.exe
2.51	2.51	40 950	0x000000000004016d0	SASMprog_rsws.exe
0.63	0.01	2 540	0x000000000004871560	(unknown)
0.63	0.63	2 540	__memset_avx2_unaligned_erms	libc-2.31.so: memset-vec-unal
0.13	0.00	1	_dl_start	ld-2.31.so: rtld.c, dl-machine.h
0.13	0.00	1	_dl_sysdep_start	ld-2.31.so: dl-sysdep.c, dl-sysc
0.10	0.00	1	dl_main	ld-2.31.so: rtld.c, get-dynamic
0.09	0.00	5	_dl_runtime_resolve_xsave	ld-2.31.so: dl-trampoline.h
0.08	0.00	1	0x00000000000401e8c	SASMprog_rsws.exe
0.08	0.00	2	0x00000000000401ea5	SASMprog_rsws.exe
0.08	0.00	2	_IO_file_xsputn@@GLIBC_2.2.5	libc-2.31.so: fileops.c, libioP.h
0.08	0.00	3	_IO_file_overflow@@GLIBC_2.2.5	libc-2.31.so: fileops.c
0.08	0.00	1	_IO_doallocbuf	libc-2.31.so: genops.c, libioP.h
0.08	0.00	1	_IO_file_dalloc	libc-2.31.so: filedoalloc.c, libio
0.08	0.00	1	0x000000000004871310	(unknown)
0.08	0.00	1	malloc	libc-2.31.so: malloc.c
0.08	0.00	1	malloc_hook_ini	libc-2.31.so: hooks.c, arena.c, i
0.08	0.03	4	_dl_relocate_object	ld-2.31.so: dl-reloc.c, dl-mach
0.08	0.00	1	ptmalloc_init.part.0	libc-2.31.so: arena.c, malloc.c
0.08	0.08	1	_dl_addr	libc-2.31.so: dl-addr.c
0.07	0.07	1	0x00000000000401767	SASMprog_rsws.exe
0.05	0.02	95	_dl_lookup_symbol_x	ld-2.31.so: dl-lookup.c
0.03	0.02	95	do_lookup_x	ld-2.31.so: dl-lookup.c, ldsode
0.03	0.03	1	__GI__tunables_init	ld-2.31.so: dl-tunables.c, dl-tu
0.01	0.00	3	0x000000000004001090	(unknown)
0.01	0.00	3	_dl_catch_exception	ld-2.31.so: dl-error-skeleton.c
0.01	0.00	3	_dl_map_object	ld-2.31.so: dl-load.c
0.01	0.01	2 758	0x00000000000401a38	SASMprog_rsws.exe
0.01	0.01	87	check_match	ld-2.31.so: dl-lookup.c
0.01	0.00	1	_dl_map_object_deps	ld-2.31.so: dl-deps.c, scratch_t
0.01	0.00	2	openaux	ld-2.31.so: dl-deps.c
0.00	0.00	151	strcmp	ld-2.31.so: strcmp.S
0.00	0.00	7	_dl_fixup	ld-2.31.so: dl-runtime.c, dl-ma
0.00	0.00	2	_dl_map_object_from_fd	ld-2.31.so: dl-load.c, dl-fileid.f
0.00	0.00	1	handle_preload_list	ld-2.31.so: rtld.c
0.00	0.00	1	0x0000000000040010f0	(unknown)
0.00	0.00	1	_dl_catch_error	ld-2.31.so: dl-error-skeleton.c
0.00	0.00	1	map_doit	ld-2.31.so: rtld.c
0.00	0.00	1	_dl_receive_error	ld-2.31.so: dl-error-skeleton.c
0.00	0.00	1	version_check_doit	ld-2.31.so: rtld.c
0.00	0.00	1	_dl_check_all_versions	ld-2.31.so: dl-version.c
0.00	0.00	4	_dl_check_map_versions	ld-2.31.so: dl-version.c
0.00	0.00	1	_dl_init	ld-2.31.so: dl-init.c
0.00	0.00	1	call_init.part.0	ld-2.31.so: dl-init.c
0.00	0.00	1	_dl_init_paths	ld-2.31.so: dl-load.c
0.00	0.00	1	init_cacheinfo	libc-2.31.so: cacheinfo.c
0.00	0.00	2	_dl_runtime_resolve_xsave/2	ld-2.31.so: dl-trampoline.h
0.00	0.00	3	handle_intel.constprop.0	libc-2.31.so: cacheinfo.c
0.00	0.00	1	open_path	ld-2.31.so: dl-load.c
0.00	0.00	1	_dl_load_cache_lookup	ld-2.31.so: dl-cache.c, dl-proci
0.00	0.00	14	_dl_name_match_p	ld-2.31.so: dl-misc.c
0.00	0.00	6	intel_check_word.isra.0	libc-2.31.so: cacheinfo.c, stdlit
0.00	0.00	1	exit	libc-2.31.so: exit.c
0.00	0.00	1	_run_exit_handlers	libc-2.31.so: exit.c, lowlevelloc
0.00	0.00	3	_dl_new_object	ld-2.31.so: dl-object.c

callgrind\_rsws.out.31092 [1] - Total Cycle Estimation Cost: 92 859 398

C:\Users\Blue-Glass\Desktop\callgrind\_simd\_rsws\_unoptimized.out.31135 [/SASMprog\_simd\_rsws\_unoptimize

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Search: (No Grouping)

Incl.	Self	Called	Function	Location
100.00	0.00	(0)	0x0000000000001100	ld-2.31.so
99.86	0.00	1	_start	SASMprog_simd_rsws_unoptimized.exe
99.86	0.00	1	(below main)	libc-2.31.so: libc-start.c
99.86	0.00	1	0x00000000000401190	SASMprog_simd_rsws_unoptimized.exe
98.69	0.00	1	0x0000000000040134b	SASMprog_simd_rsws_unoptimized.exe
98.68	0.00	10	0x000000000004013d9	SASMprog_simd_rsws_unoptimized.exe
97.29	5.63	81 900	0x000000000004013d9'2	SASMprog_simd_rsws_unoptimized.exe
46.51	4.01	81 910	memalign	libc-2.31.so: malloc.c
42.50	6.92	81 911	_int_memalign	libc-2.31.so: malloc.c
33.74	22.17	163 813	_int_malloc	libc-2.31.so: malloc.c
23.94	23.91	246 514	_int_free	libc-2.31.so: malloc.c
19.77	4.01	163 810	free	libc-2.31.so: malloc.c
14.21	7.20	81 899	calloc	libc-2.31.so: malloc.c
11.37	8.09	628	malloc_consolidate	libc-2.31.so: malloc.c
6.83	5.39	40 950	0x00000000000401517	SASMprog_simd_rsws_unoptimized.exe
3.51	3.51	161 404	unlink_chunk.isra.0	libc-2.31.so: malloc.c
3.01	3.01	40 950	0x00000000000401702	SASMprog_simd_rsws_unoptimized.exe
2.72	2.72	40 950	0x000000000004016e5	SASMprog_simd_rsws_unoptimized.exe
1.08	0.92	1	0x000000000004017f1	SASMprog_simd_rsws_unoptimized.exe
0.78	0.78	51 200	0x00000000000402169	SASMprog_simd_rsws_unoptimized.exe
0.68	0.01	2 540	0x000000000004871560	(unknown)
0.68	0.68	2 540	__memset_avx2_unaligned_erms	libc-2.31.so: memset-vec-unaligned-er...
0.66	0.66	51 200	0x00000000000402174	SASMprog_simd_rsws_unoptimized.exe
0.15	0.15	44 097	0x00000000000401a4d	SASMprog_simd_rsws_unoptimized.exe
0.14	0.00	1	_dl_start	ld-2.31.so: rtld.c, dl-machine.h, get-dy...
0.14	0.00	1	_dl_sysdep_start	ld-2.31.so: dl-sysdep.c, dl-sysdep.c, cp...
0.11	0.00	1	dl_main	ld-2.31.so: rtld.c, get-dynamic-info.h, s...
0.10	0.00	5	_dl_runtime_resolve_xsave	ld-2.31.so: dl-trampoline.h
0.09	0.00	1	0x00000000000401ea1	SASMprog_simd_rsws_unoptimized.exe
0.09	0.00	2	0x00000000000401eba	SASMprog_simd_rsws_unoptimized.exe
0.09	0.00	2	_IO_file_xsputn@@GLIBC_2.2.5	libc-2.31.so: fileops.c, libioP.h
0.09	0.00	3	_IO_file_overflow@@GLIBC_2.2.5	libc-2.31.so: fileops.c
0.09	0.00	1	_IO_doallocbuf	libc-2.31.so: genops.c, libioP.h
0.09	0.00	1	_IO_file_doallocate	libc-2.31.so: filedoalloc.c, libioP.h, sys...
0.09	0.00	1	0x000000000004871310	(unknown)
0.09	0.00	1	malloc	libc-2.31.so: malloc.c
0.09	0.00	1	malloc_hook_ini	libc-2.31.so: hooks.c, arena.c, malloc.c
0.09	0.03	4	_dl_relocate_object	ld-2.31.so: dl-reloc.c, dl-machine.h, do...
0.09	0.00	1	ptmalloc_init.part.0	libc-2.31.so: arena.c, malloc.c
0.08	0.08	1	_dl_addr	libc-2.31.so: dl-addr.c
0.06	0.02	95	_dl_lookup_symbol_x	ld-2.31.so: dl-lookup.c
0.04	0.03	95	do_lookup_x	ld-2.31.so: dl-lookup.c, ldsdefs.h
0.03	0.03	1	_GI__tunables_init	ld-2.31.so: dl-tunables.c, dl-tunables.h
0.01	0.00	3	0x000000000004001090	(unknown)
0.01	0.00	3	_dl_catch_exception	ld-2.31.so: dl-error-skeleton.c
0.01	0.00	3	_dl_map_object	ld-2.31.so: dl-load.c
0.01	0.01	87	check_match	ld-2.31.so: dl-lookup.c
0.01	0.00	1	_dl_map_object_deps	ld-2.31.so: dl-deps.c, scratch_buffer.h
0.01	0.00	2	openaux	ld-2.31.so: dl-deps.c
0.01	0.01	151	strcmp	ld-2.31.so: strcmp.S
0.01	0.00	7	_dl_fixup	ld-2.31.so: dl-runtime.c, dl-machine.h
0.00	0.00	2	_dl_map_object_from_fd	ld-2.31.so: dl-load.c, dl-fileid.h, dl-map...
0.00	0.00	1	handle_preload_list	ld-2.31.so: rtld.c
0.00	0.00	1	0x0000000000040010f0	(unknown)
0.00	0.00	1	_dl_catch_error	ld-2.31.so: dl-error-skeleton.c
0.00	0.00	1	map_doit	ld-2.31.so: rtld.c
0.00	0.00	1	_dl_receive_error	ld-2.31.so: dl-error-skeleton.c
0.00	0.00	1	version_check_doit	ld-2.31.so: rtld.c
0.00	0.00	1	_dl_check_all_versions	ld-2.31.so: dl-version.c
0.00	0.00	4	_dl_check_map_versions	ld-2.31.so: dl-version.c
0.00	0.00	1	_dl_init	ld-2.31.so: dl-init.c
0.00	0.00	4	call_init.part.0	ld-2.31.so: dl-init.c
0.00	0.00	1	_dl_init_paths	ld-2.31.so: dl-load.c
0.00	0.00	1	init_cacheinfo	libc-2.31.so: cacheinfo.c
0.00	0.00	2	_dl_runtime_resolve_xsave'2	ld-2.31.so: dl-trampoline.h
0.00	0.00	3	handle_intel.constprop.0	libc-2.31.so: cacheinfo.c
0.00	0.00	1	open_path	ld-2.31.so: dl-load.c
0.00	0.00	1	_dl_load_cache_lookup	ld-2.31.so: dl-cache.c, dl-procinfo.h, dl...
0.00	0.00	14	_dl_name_match_p	ld-2.31.so: dl-misc.c
0.00	0.00	6	intel_check_word.isra.0	libc-2.31.so: cacheinfo.c, stdlib-bsearc...
0.00	0.00	1	exit	libc-2.31.so: exit.c
0.00	0.00	1	_run_exit_handlers	libc-2.31.so: exit.c, lowlevellock.h

callgrind\_simd\_rsws\_unoptimized.out.31135 [1] - Total Cycle Estimation Cost: 85 811 196

C:\Users\Blue-Glass\Desktop\callgrind\_simd\_rsws.out.31124 [/SASMprog\_simd\_rsws.exe ./output.wav]

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Cycle Estimation

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Search: (No Grouping)

Incl.	Self	Called	Function	Location
100.00	0.00	(0)	0x0000000000001100	ld-2.31.so
99.86	0.00	1	_start	SASMprog_simd_rsws.exe
99.86	0.00	1	(below main)	libc-2.31.so: libc-start.c
99.86	0.00	1	0x000000000000401190	SASMprog_simd_rsws.exe
99.68	0.00	1	0x00000000000040134b	SASMprog_simd_rsws.exe
99.68	0.00	10	0x0000000000004013d9	SASMprog_simd_rsws.exe
98.27	5.69	81 900	0x0000000000004013d9'2	SASMprog_simd_rsws.exe
46.98	4.05	81 910	memalign	libc-2.31.so: malloc.c
42.93	6.99	81 911	_int_memalign	libc-2.31.so: malloc.c
34.08	22.39	163 813	_int_malloc	libc-2.31.so: malloc.c
24.18	24.16	246 514	_int_free	libc-2.31.so: malloc.c
19.97	4.05	163 810	free	libc-2.31.so: malloc.c
14.36	7.27	81 899	calloc	libc-2.31.so: malloc.c
11.48	8.17	628	malloc_consolidate	libc-2.31.so: malloc.c
6.89	5.45	40 950	0x000000000000401517	SASMprog_simd_rsws.exe
3.55	3.55	161 404	unlink_chunk.isra.0	libc-2.31.so: malloc.c
3.04	3.04	40 950	0x000000000000401702	SASMprog_simd_rsws.exe
2.75	2.75	40 950	0x0000000000004016e5	SASMprog_simd_rsws.exe
0.78	0.78	51 200	0x000000000000402169	SASMprog_simd_rsws.exe
0.69	0.01	2 540	0x0000000000004871560	(unknown)
0.68	0.68	2 540	__memset_avx2_unaligned_erms	libc-2.31.so: memset-vec-unaligned-erms.S
0.66	0.66	51 200	0x000000000000402174	SASMprog_simd_rsws.exe
0.14	0.00	1	_dl_start	ld-2.31.so: rtld.c, dl-machine.h, get-dynamic...
0.14	0.00	1	_dl_sysdep_start	ld-2.31.so: dl-sysdep.c, dl-sysdep.c, cpu-feat...
0.11	0.00	1	dl_main	ld-2.31.so: rtld.c, get-dynamic-info.h, setup...
0.10	0.00	5	_dl_runtime_resolve_xsave	ld-2.31.so: dl-trampoline.h
0.09	0.00	1	0x000000000000401ea1	SASMprog_simd_rsws.exe
0.09	0.00	2	0x000000000000401eba	SASMprog_simd_rsws.exe
0.09	0.00	2	_IO_file_xsputn@@GLIBC_2.2.5	libc-2.31.so: fileops.c, libioP.h
0.09	0.00	3	_IO_file_overflow@@GLIBC_2.2.5	libc-2.31.so: fileops.c
0.09	0.00	1	_IO_doaallocbuf	libc-2.31.so: genops.c, libioP.h
0.09	0.00	1	_IO_file_doallocate	libc-2.31.so: filedoalloc.c, libioP.h, sysmacros.h
0.09	0.00	1	0x0000000000004871310	(unknown)
0.09	0.00	1	malloc	libc-2.31.so: malloc.c
0.09	0.00	1	malloc_hook_ini	libc-2.31.so: hooks.c, arena.c, malloc.c
0.09	0.03	4	_dl_relocate_object	ld-2.31.so: dl-reloc.c, dl-machine.h, do-rel.h, ...
0.09	0.00	1	ptmalloc_init.part.0	libc-2.31.so: arena.c, malloc.c
0.09	0.08	1	_dl_addr	libc-2.31.so: dl-addr.c
0.08	0.07	1	0x00000000000040177c	SASMprog_simd_rsws.exe
0.06	0.02	95	_dl_lookup_symbol_x	ld-2.31.so: dl-lookup.c
0.04	0.03	95	do_lookup_x	ld-2.31.so: dl-lookup.c, ldsodefs.h
0.03	0.03	1	_GI__tunables_init	ld-2.31.so: dl-tunables.c, dl-tunables.h
0.01	0.00	3	0x0000000000004001090	(unknown)
0.01	0.00	3	_dl_catch_exception	ld-2.31.so: dl-error-skeleton.c
0.01	0.00	3	_dl_map_object	ld-2.31.so: dl-load.c
0.01	0.01	2 758	0x000000000000401a4d	SASMprog_simd_rsws.exe
0.01	0.01	87	check_match	ld-2.31.so: dl-lookup.c
0.01	0.00	1	_dl_map_object_deps	ld-2.31.so: dl-deps.c, scratch_buffer.h
0.01	0.00	2	openaux	ld-2.31.so: dl-deps.c
0.01	0.01	151	strcmp	ld-2.31.so: strcmp.S
0.01	0.00	7	_dl_fixup	ld-2.31.so: dl-runtime.c, dl-machine.h
0.00	0.00	2	_dl_map_object_from_fd	ld-2.31.so: dl-load.c, dl-fileid.h, dl-map-seg...
0.00	0.00	1	handle_preload_list	ld-2.31.so: rtld.c
0.00	0.00	1	0x00000000000040010f0	(unknown)
0.00	0.00	1	_dl_catch_error	ld-2.31.so: dl-error-skeleton.c
0.00	0.00	1	map_doit	ld-2.31.so: rtld.c
0.00	0.00	1	_dl_receive_error	ld-2.31.so: dl-error-skeleton.c
0.00	0.00	1	version_check_doit	ld-2.31.so: rtld.c
0.00	0.00	1	_dl_check_all_versions	ld-2.31.so: dl-version.c
0.00	0.00	4	_dl_check_map_versions	ld-2.31.so: dl-version.c
0.00	0.00	1	_dl_init	ld-2.31.so: dl-init.c
0.00	0.00	4	call_init.part.0	ld-2.31.so: dl-init.c
0.00	0.00	1	_dl_init_paths	ld-2.31.so: dl-load.c
0.00	0.00	1	init_cacheinfo	libc-2.31.so: cacheinfo.c
0.00	0.00	2	_dl_runtime_resolve_xsave2	ld-2.31.so: dl-trampoline.h
0.00	0.00	3	handle_intel.constprop.0	libc-2.31.so: cacheinfo.c
0.00	0.00	1	open_path	ld-2.31.so: dl-load.c
0.00	0.00	1	_dl_load_cache_lookup	ld-2.31.so: dl-cache.c, dl-procinfo.h, dl-cach...
0.00	0.00	14	_dl_name_match_p	ld-2.31.so: dl-misc.c
0.00	0.00	6	intel_check_word.isra.0	libc-2.31.so: cacheinfo.c, stdlib-bsearch.h
0.00	0.00	1	exit	libc-2.31.so: exit.c
0.00	0.00	1	__run_exit_handlers	libc-2.31.so: exit.c, lowlevellock.h

callgrind\_simd\_rsws.out.31124 [1] - Total Cycle Estimation Cost: 84 954 059

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- <sup>i</sup> Cooley, J. and Tukey, J. (1965) "An algorithm for the machine calculation of complex Fourier series", Mathematics of Computation, 19(90), pp. 297-301. doi: 10.1090/s0025-5718-1965-0178586-1.
- <sup>ii</sup> SASM - Simple crossplatform IDE for NASM, MASM, GAS, FASM assembly languages (2021). Available at: <https://dman95.github.io/SASM/english.html> (Accessed: 28 December 2021).
- <sup>iii</sup> [03/10] Improve performance of sinf and cosf - Patchwork (2021). Available at: <https://patchwork.ozlabs.org/project/glibc/patch/480576b5-fbb7-39b2-d80c-80c8931fde21@arm.com/#1973677> (Accessed: 28 December 2021).
- <sup>iv</sup> Soft float library routines (GNU Compiler Collection (GCC) Internals) (2021). Available at: <https://gcc.gnu.org/onlinedocs/gccint/Soft-float-library-routines.html> (Accessed: 28 December 2021).